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A COMPARISON OF THE SECOND DERIVATIVE METHOD OF GRAVITY INTERPRETATION WITH REFLECTION SEISMICS AND GEOLOGICAL FINDINGS IN THE OFFENBURG AREA *

BY

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WITH CONTRIBUTIONS BY:

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ABSTRACT

The aim of the present investigation is to examine the significance of the second derivative for the purpose of the prospective determination of the geological properties of the district of Offenburg, which are relatively wellknown as a result of both reflection seismic and bore profile findings.

The calculation of the second derivative is carried out by means of three approximation formulae, which are compared with each other. In contrast to the isogam map the second derivative shows some additional characteristics, whose structural significance illuminates the comparison with the results of reflection seismics.

A geological profile constructed on the basis of 6 wells completely confirms the geophysical findings.

INTRODUCTION

The evaluation of the second derivative of the Bouguer anomaly in the direction of the vertical is carried out with the purpose of eliminating to a large extent the so-called regional effect, in order to stress the effect of local density disturbance. The success which can thus be achieved is shown by the remarkable results of an exceedingly interesting paper by Elkins (1951). — Going beyond this one would expect that the second derivative would possess a higher resolving power as regards the Bouguer anomaly itself when localising geological structures; for this is already shown by the vertical gradient, i.e. the first derivative of the Bouguer anomaly in the direction of the vertical (Evjen-1936).

The present paper is dealing with a study of the second derivative in the Offenburg district in order that its significance in connection with geophysical

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prospecting may be recognised. As is evident from the location map of this area (Fig. 1) seismic and gravimetric methods had been applied and a few wells had been drilled. Accordingly our investigation can be naturally subdivided into three sections:

- Part I consists of a discussion of the formulae used to evaluate the second derivative as well as a discussion of their results;
- Part II contains the essential results of the reflection seismic survey, which are then compared with the second derivative;
- Part III deals with the geology of the area on the basis of information obtained from the wells, so that we are enabled to check the geophysical results of Part I and II.

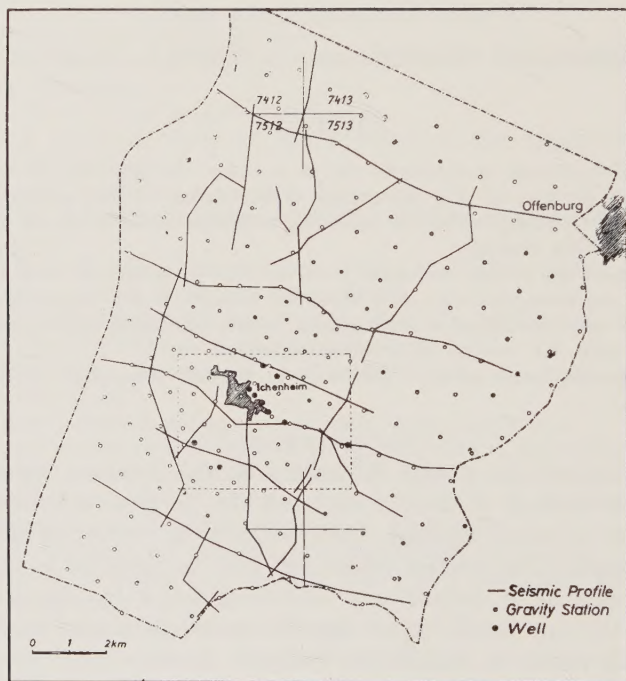


Fig. 1. Offenburg-Location Map.
(The Ichenheim region is exhibited in enlarged form in fig. 16).

I. THE EVALUATION OF THE SECOND DERIVATIVE AND ITS RESULTS

Suppose that the Bouguer anomaly, to be denoted by g , is known in a horizontal xy -plane. Then it is possible to evaluate approximately the second derivative of the Bouguer anomaly in the vertical z -direction at the origin of the coordinate system, using the values of g in the neighbourhood of the origin.

The paper of Elkins to which we have referred above gives a method of deriving such approximation formulae. These various formulae yield by no

means equally good results. Elkins therefore decided on a "standard" formula, by means of which his remarkable practical examples had been computed. The gravitational values g^P , g^A_i ($i = 1 \dots 4$), g^B_i ($i = 1 \dots 4$), g^C_i ($i = 1 \dots 8$), which enter this formula correspond to the points of the configuration of Fig. 2; and the formula yields a value of the second derivative g^P_{zz} for the point P according to the approximative expression:

$$g^P_{zz} \approx \frac{1}{62 s^2} \left[44 g^P + 4 \sum_{i=1}^4 g^A_i - 3 \sum_{i=1}^4 g^B_i - 6 \sum_{i=1}^8 g^C_i \right] \quad (1)$$

By means of a check on synthetic examples it became clear that points for which the second derivative attains extreme values were given only very imperfectly by (1).

This fact led Rosenbach (1953) to give a basically different method of deriving

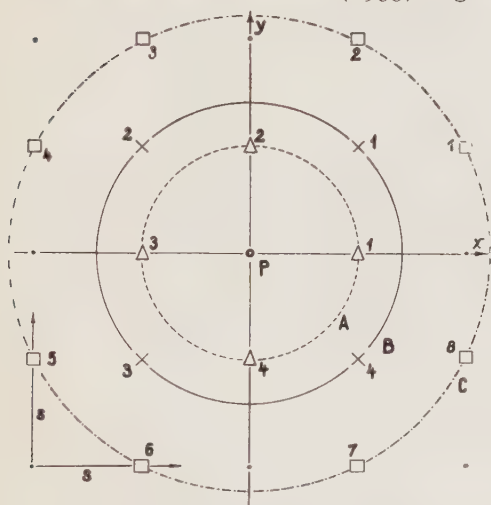


Fig. 2: Point configuration composed of arrangement "A": -- $\triangle$ --

" " "B": -- + --

" " "C": -- $\square$ --

Formulae (1) and (2) are based on this point configuration.

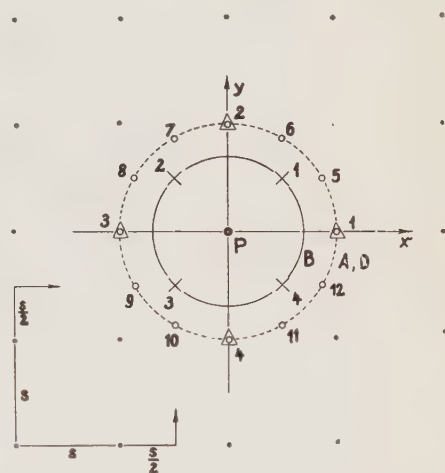


Fig. 3: Point configuration, composed of arrangement "A": -- $\triangle$ --

" " "B": -- + --

" " "D": -- $\circ$ --

Formula (3) is based on this point configuration.

approximation formulae for the second derivative. On using the gravitational values at the points of the configuration of Fig. 2 the second derivative is accordingly given by

$$g^P_{zz} \approx \frac{1}{24 s^2} \left[96 g^P - 18 \sum_{i=1}^4 g^A_i - 8 \sum_{i=1}^4 g^B_i + \sum_{i=1}^8 g^C_i \right] \quad (2)$$

If on the other hand, the values of g in the points of the configuration of Fig. 3 are used, the following expression is obtained:

$$g_{zz}^P \approx \frac{1}{s^2} \left[12 g^P - \sum_{i=1}^4 g_{i1}^A - 4 \sum_{i=1}^4 g_{i1}^B + \frac{2}{3} \sum_{i=1}^{12} g_{i1}^D \right] \quad (3)$$

As Rosenbach (1953) has shown by means of synthetic examples, these formulae may be characterised as follows:

Formula (3) yields good quantitative values of the second derivative, but is necessarily sensitive as regards errors of the gravitational values used.

Formula (2) does not yield equally good extreme values of the second

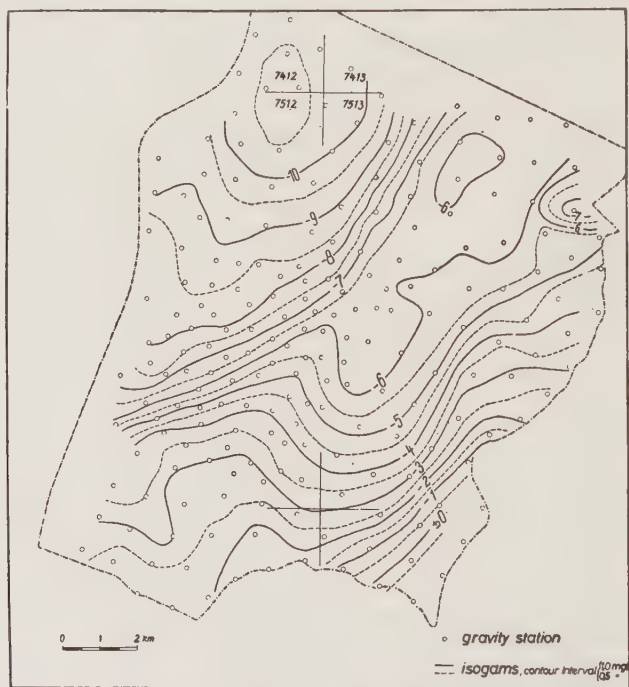


Fig. 4. Offenburg — Bouguer-Anomalies.

derivative as compared to (3), but considerably better than formula (1), which uses the *same* gravitational values as (2).

In order to have at our disposal a practical example for the purpose of comparison, all three formulae have been applied to the calculation of the second derivative in the district of Offenburg, with $s = 1$ km.

The basis for the application of these formulae is the isogam map (Fig. 4). The stations are not situated so that a quadratic grid is obtained. Thus it was necessary to compute the gravitational values for such a grid by means of interpolation and the construction of gravity profiles. This obviously involves errors in the gravitational values, which enter the formulae. In order to reduce

these errors, the interpolation was carried out as far as possible in the direction of the isogams in the course of the computation.

Before we turn to a discussion of the results of the calculations a few remarks concerning the isogam map should be made:

In the north-west of the area under investigation there is a closed gravitational minimum of -10.5 mgals, from which a gravity increase develops towards the south, south-east and east, which is very clearly represented by a bundle of very close isogams. This is followed towards the east in the northern

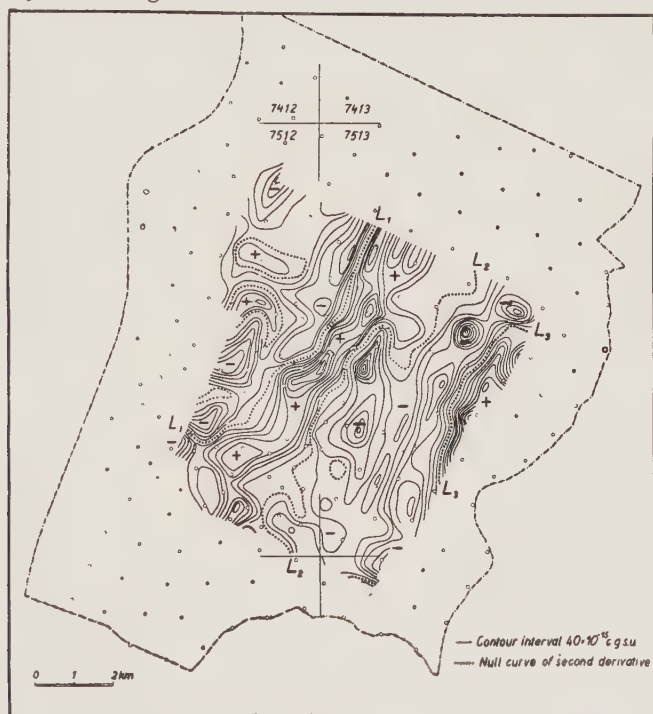


Fig. 5. Offenburg — Second Derivative according to formula (3).

half of the area by a broad strip of almost constant anomaly values of an order of magnitude of -6 mgals. From here gravity increases once more towards the south-west, after which it is represented by a not very clearly defined gravitational plateau with values between -3 and -2 mgals. Finally a marked increase in gravitational values is displayed by the rest of the area, in particular in a south-eastern direction.

An interpretation of the isogam map may roughly be given as follows: The layers of higher density responsible for the gravitational anomalies are situated

1. rather deeply in the area of the north-western gravitational minimum,
2. higher in the area of the north-eastern gravitational plateau,
3. still higher in the area of the south-western gravitational plateau

and continue to rise towards the south-east. In this sense we shall speak of

1. the north-western downthrown block.
2. the eastern heaved block and
3. the southern heaved block.

The characteristic bulge of the isogams towards the north in the central field of the area under investigation indicates a higher position of the layers relative to the eastern heaved block.

The reason for the difference in depth between individual blocks is given

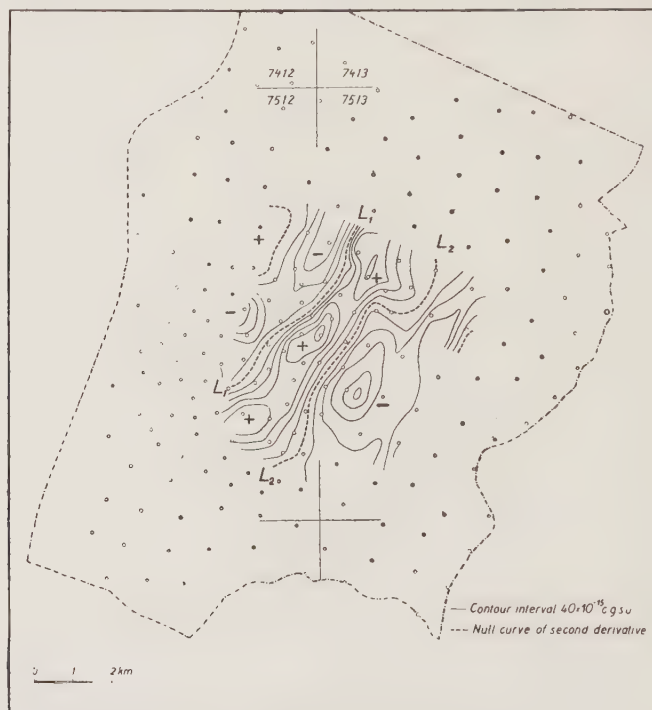


Fig. 6. Offenburg — Second Derivative according to formula (2).

by faults of various directions. A disturbance passes through the northern part of the area in the direction north-east to south-west. There are however one or more cross-disturbances in the south, running in a western direction, whose closer localisation seems more or less impossible. This applies even more to the mass deposits in the region of the isogam bulges of the central field. On the other hand, it is easy to interpret the increase in gravity in the south-east: it is caused by the main fault of the Black Forest.

Since the delineation of the chief geological structural elements is somewhat difficult, it would seem that an attempt to interpret local peculiarities of the isogam map would be more or less hopeless. In contrast to this, the question

arises as to whether the second derivative can promise us more hope of success in the prospective determination of geological properties.

Let us turn therefore to the maps of the second derivative, which have been obtained by means of the given formulae. An examination in the order of sequence of formulae (3), (2), (1) immediately shows the following conspicuous state of affairs: The second derivative according to formula (3), Fig. 5, displays considerable variations of its values. On the other hand the second derivative according to formula (2), Fig. 6, shows a smaller variation

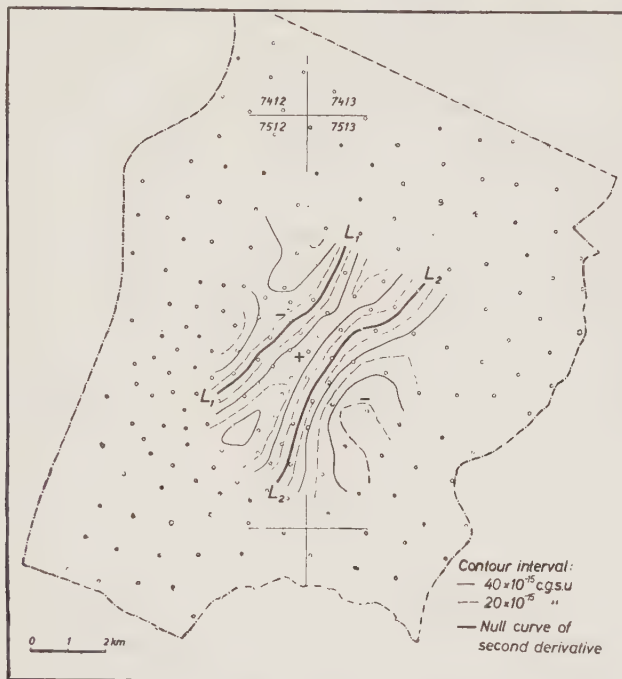


Fig. 7. Offenburg — Second Derivative according to formula (1).

in the distribution of its values. Finally we note that formula (1) (according to Fig. 7) yields an even less distinguishing picture. — As a result of this preliminary comparison we consequently conclude that the distribution of values of the second derivative is smoothed out considerably in the sense of the sequence of the formulae applied. This result is not surprising in the light of the discussion of the characteristics of these formulae of approximation as given at the beginning.

We shall now discuss individual characteristics of the three maps. Those curves, for which the second derivative assumes the value zero, are in general of particular importance; for according to theory the second derivative vanishes for vertical faults precisely above the edge, while for inclined—but not too

sloping—faults the second derivative vanishes virtually above the upper edge. Thus the curves of vanishing second derivative have been marked specially in these three maps.

Let us return to the first map of the second derivative in Fig. 5, which was evaluated by means of formula (3): We immediately note the three null-curves L_1 , L_2 , L_3 which will be interpreted in the sequence L_1 , L_3 , L_2 .

Corresponding to the interpretation of the isogam map L_1 should belong to the delineation between the downthrown block in the north-west and the eastern heaved block. The sudden change of direction of L_1 in the south is remarkable and might possibly be due to a cross-disturbance. Due to computational difficulties it was not possible to follow up L_1 towards the west, so that the possible cause mentioned here should be accepted sceptically.

The curve L_3 localises the fault between the eastern heaved block and the layers situated higher towards the east.

For this sequence of two faults which position is indicated by L_1 and L_3 respectively there should exist a further null-curve between L_1 and L_3 according to theory, which has no direct structural significance. In fact a curve L_2 is displayed in the map, L_2 being situated however in the north nearer to L_3 , after which it is suddenly displaced towards the west, so that its southern part proceeds nearer to L_1 . Then L_2 clearly turns off towards the east. — In view of these peculiarities, the following questions arise:

1. whether the parallel displacement of the northern and southern part of L_2 is due to structural causes;
2. whether the southern part of L_2 is in any way related to the raised layers in the central field, where, as we have noted above, the isogams display a characteristic bulge towards the north;
3. whether the obvious change of direction of L_2 in the south towards the east is caused by the boundary between the eastern and southern heaved blocks.

The theory predicts that L_2 should be roughly parallel to L_1 and L_3 if there were an undisturbed mass deposit between L_1 and L_3 . Thus structural reasons will certainly determine the cause of L_2 , namely those which also cause the bulge towards the north of the isogams in the central field.

Apart from the curves L_1 , L_2 , L_3 the figure displays two closely situated maxima in the north-west, each surrounded by null-curves. But in this area we observe from the isogam map that the isogams are displaced locally towards the north, thus deviating from the general tendency. This effect of the Bouguer anomaly as well as the distribution of signs of the second derivative seem to indicate a positive density disturbance, about whose depth nothing can be said immediately.

The null-curves discussed here form the limits of maxima and minima of the second derivative, which are of different extensions and orders of magnitude. Their numerical values will be mentioned on a suitable occasion below.

At the moment we wish to determine by means of a comparison whether the characteristics of Fig. 5 pointed out above also occur in Figs. 6 and 7. In order to be able to compare the relative positions of the individual null-curves, we have drawn them together in Fig. 8. Unfortunately the boundary strip, for which the second derivative cannot be calculated, is larger for the formulae (1) and (2) than for the sensitive formula (3) in view of computational reasons, as is easily seen by a glance at the configurations in Figs 2 and 3. This leads to an unfavourable restriction as regards the possibilities of comparison.

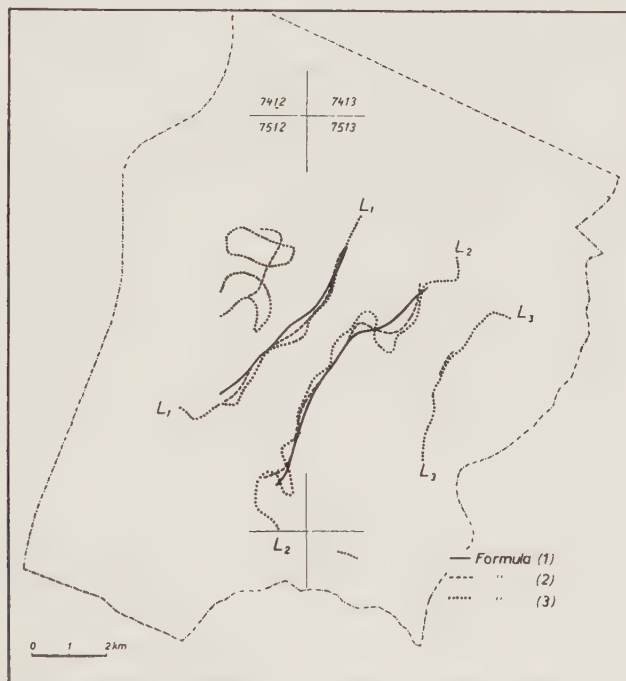


Fig. 8. Offenburg — Null curves of Second Derivative.

Thus for example the curve L_3 falls into this boundary zone, i.e. L_3 cannot be dealt with at all by formulae (2) and (3). — The *null-curves* L_1 coincide very well in so far as they are available, but unfortunately the sharp angle of L_1 according to the sensitive formula (3) also falls within the extended boundary zone of the other two formulae. The parallel displacement of L_2 is brought out most markedly by formula (3) and most weakly by formula (1). — The null-curves in the north-western area are most conspicuous: The sensitive formula (3) displays two null-curves, the less sensitive formula (2) one, whereas (1), the standard formula of Elkins, displays none at all. This phenomenon is probably explained sufficiently by the following hint: For-

mulae (1) and (2) use gravitational values at points rather more distant from the point for which the second derivative is to be evaluated, in contrast to formula (3). Thus it seems plausible that the less sensitive formula (2) yields a single indistinct smudge of the two null-curves. In distinction to this the standard formula of Elkins seems to be too insensitive to work out the null-curve and the area which it encloses.

Summarising, we may say that the map of the second derivative, in particular

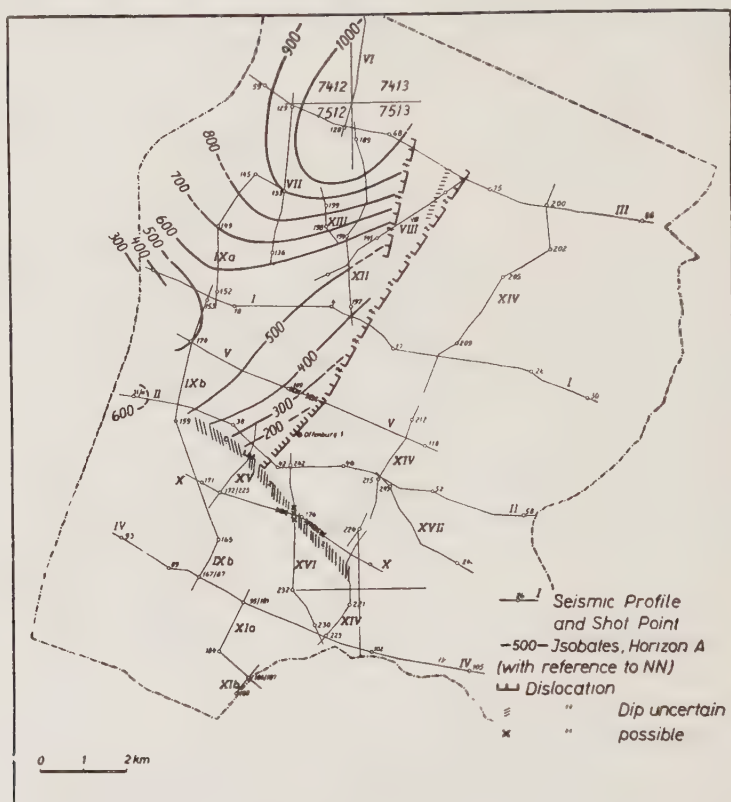


Fig. 9. Offenburg — Contour Map of tertiary horizon A (referred to sea level) as well as disturbances determined seismically.

the one calculated according to formula (3), displays additional characteristic features when compared with the isogam map. The structural significance of these features will have to be explained. For this purpose we shall compare gravimetric results with those of reflection seismics in the next section.

11. THE FINDINGS OF REFLECTION SEISMICS AS COMPARED WITH THOSE OF GRAVITY MEASUREMENTS

The essential results of the reflection seismic survey are exhibited in Fig. 9,

which shows the contour map of the tertiary horizon A, in which for the sake of orientation the profiles and a few shot points as well as the wildcat Offenburg 1 have been marked. In order to attain a smooth continuation with the area of Rastatt further north, the velocity diagram, which had been used there, was used for the computation of horizon depths.

The contour map represents the tertiary horizon A as far as it is possible to follow the latter continuously. Also, in Fig. 9, all disturbing elements have been marked, which can be recognised on the seismograms and from the reflecting elements in the profiles. — Accordingly the object investigated divides itself

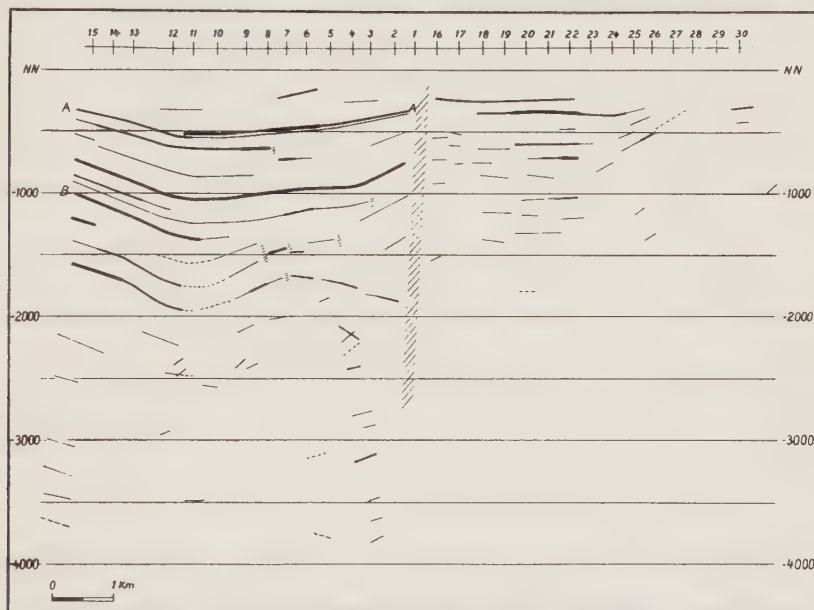


Fig. 10. Offenburg — Reflexion Seismic Profile I.

up into three tectonically different parts: An essentially undisturbed, but very much folded, downthrown block in the north-west is separated by a disturbance running NE-SW from an eastern heaved block, and also from a southern heaved block by a disturbance running NW-SE. Since relatively high velocities could be attained by refraction seismics at low depths on the southern heaved block, the latter is probably situated higher than the eastern heaved block.

The dip of the disturbances could not be determined by correlation of horizons on either side of the disturbances. However according to Figs. 10-13 the reflecting elements in the profiles I, II, III and V show quite unambiguously that the eastern block must be situated considerably higher than the north-western block.

The directions of the disturbances as given in Fig. 9 are doubtful within

certain limits, since they have been only deduced from the reflecting elements in the profiles. This is true in particular of the disturbances between profiles I and III. It appears however that the NE-SW disturbance, which has been drawn continuously, would approximately represent the western boundary of the eastern heaved block.

In profile I, Fig. 10, an uplift within the downthrown block is remarkable. It may be caused either by a salt or by a basalt dome.

In the south-east of the downthrown block, i.e. in its highest part, a few smaller disturbances may possibly exist in front of the main disturbances. In

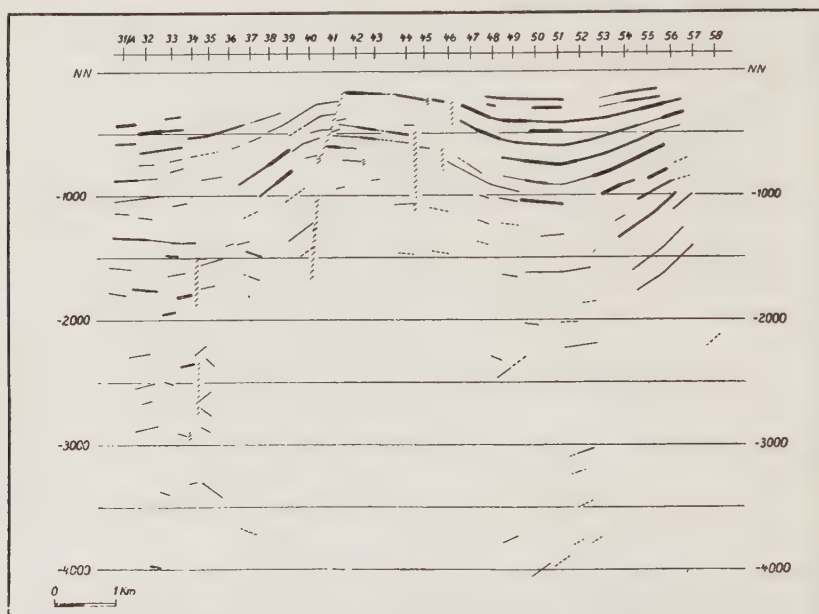


Fig. 11. Offenburg — Reflexion Seismic Profile II.

particular, the reflecting elements in profile V, Fig. 13, east of shot point 109 seem to indicate this. Also, no continuous horizons could be obtained in profile II, Fig. 11, west of the disturbance under shot point 41. Therefore it is well possible that in this region the NE-SW disturbance as drawn in Fig. 9 would represent the beginnings of a fractured zone, similar to the one indicated further northward.

How do these results obtained by reflection seismics agree with the map of the second derivative? In order to answer this question we have drawn in Fig. 14 the essential disturbing elements of the contour map together with the null-curves of Fig. 5.

From this representation it can be clearly seen that the null-curve L_1 follows the disturbances between the northwestern downthrown block and the two

heaved blocks. Displacements relative to each other are not caused solely by the necessarily inexact values of the second derivative, as is obvious from a consideration of the seismic profiles I and III: Theoretically it is clear that the disturbance and L_1 coincide for the seismic profile I (Fig. 10), since we are dealing here with a vertical fault, gravimetrically speaking. On the other hand, the disturbance cannot coincide with L_1 for the seismic profile III (Fig. 12), since here the fault is inclined. L_1 lies above the broken part between the two blocks, which one would expect theoretically. — It is surprising to note the

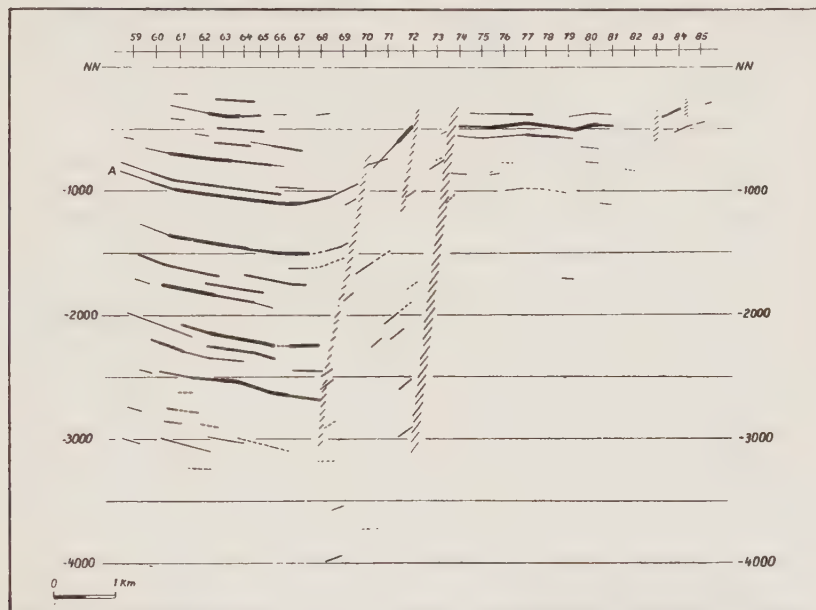


Fig. 12. Offenburger — Reflexion Seismic Profile III.

tendency of curve L_1 towards the direction of the NW-SE disturbance, which had been given seismically in the southern part of the area. It is very unfortunate that computational difficulties prevent us from following L_1 further towards the west. A glance at the isogam map (Fig. 4) shows that the crossing disturbance seems to become noticeable only further westward; while on the other hand the isogams are practically undisturbed in the immediate vicinity of the corner determined by the intersection of the two disturbances running NW-SE and NE-SW. This fact is quite plausible theoretically. Also, it is theoretically clear why the track of the null-curve L_1 should reflect conspicuously the existence of the corner. Moreover the behaviour of the values of the second derivative according to Fig. 5 in the vicinity of this corner—local minimum in the NW as well as a local maximum in the SE of the latter—is definitely in agreement with the theory.

As we have already mentioned, the null-curve L_2 displays a clear parallel displacement towards the west in its southern part in contrast to its northern part. A glance at the seismic profiles II and V (Figs. 11 and 13) shows that here the heaved block rises towards the west, which is not the case for profile I (Fig. 10). This rise of the layers must forcibly displace the null-curve L_2 in its southern part towards the west in accordance with Fig. 14; in the isogram map (Fig. 4) the characteristic bulge to the north is indicated. — As we have remarked above, the rise of the layers of the heaved block in a western direction

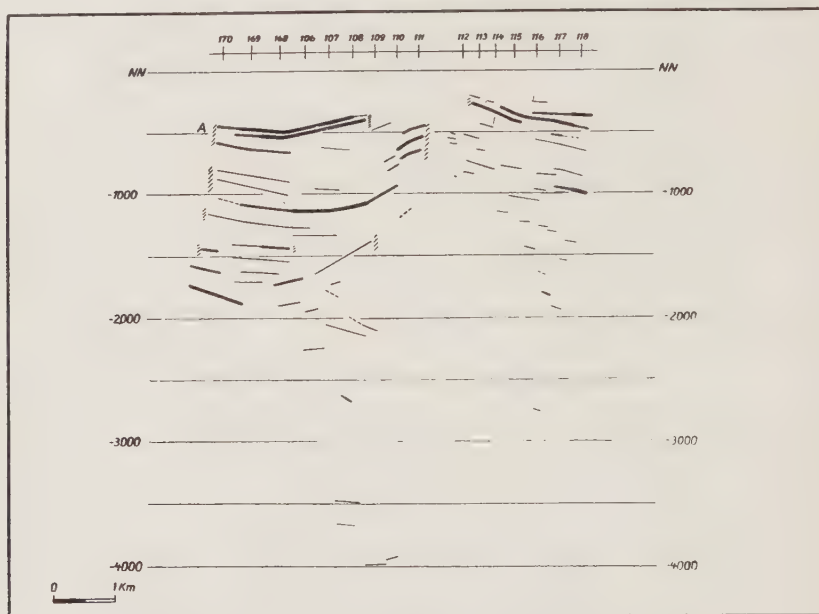


Fig. 13. Offenburg — Reflexion Seismic Profile V.

does not appear in profile I (Fig. 10) in contrast to profiles II and V (Figs. 11 and 13). The southern rise of the heaved block west of L_2 (Fig. 14), which would thus have to be located in the area between profiles I and V, should also be accompanied by a null-curve in view of theoretical reasons. This null-curve is however not developed, since it is covered by the values of the second derivative along the main disturbance. This southern rise within the heaved block will in any case serve to make the local high of the second derivative appear theoretically plausible in this area, which lies exactly on the boundary of the plane table maps 7512 and 7513.

The southern end of L_2 proceeds very unsteadily. Here the exactness of the gravitational values which enter the calculation of the second derivative has to be regarded with some doubt. It is therefore uncertain whether the tendency of

L_2 towards the east, which is very clearly recognisable here, is in any way connected with the NW-SE disturbance, which had been determined seismically. Here also it becomes impossible to follow the further course of L_2 in view of computational reasons.

Let us now consider the null-curves in the north-west (Fig. 14), i.e. the null-curves in the area above the downthrown block. The contour map (Fig. 9) gives us no hint with regard to their origin. The null-curves are due to deeper

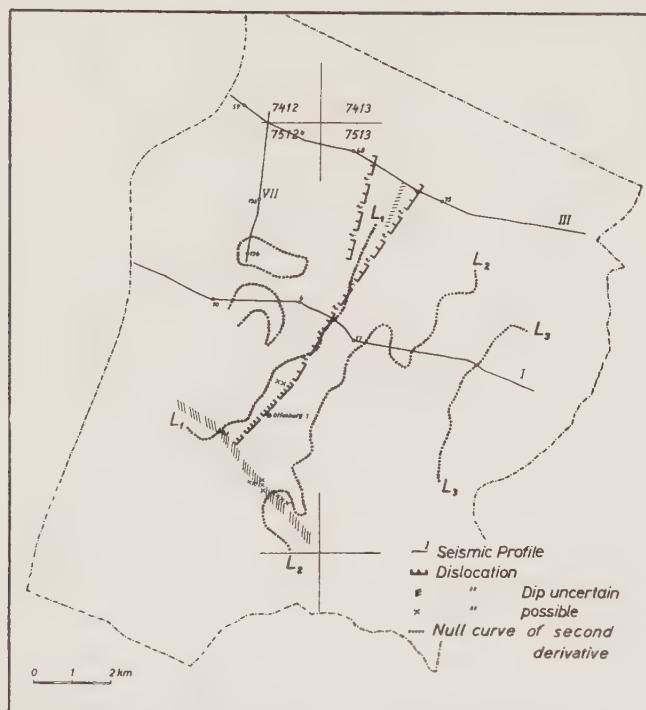


Fig. 14. Offenburg — Null curves of second derivative according to formula (3) and disturbances located seismically.

layers: In the seismic profile I (Fig. 10) there exists—as already mentioned above—a remarkable uplift within the downthrown block; the latter is also given by profile VII (Fig. 15). If the layers concerned in this uplift have a density higher than those above, the effect of the second derivative can be explained essentially by this state of affairs. According to the theory the two associated minima in the north and in the south must appear. The question as regards the reason for the two separate maxima remains open however, and therefore also the problem of the two separate null-curves. Yet we might point out that the greater depth of the uplift explains the low value of the anomaly (approx. 100×10^{-15} cgs) as compared with the one three times higher along

the main NE-SW disturbance being accompanied by L_1 ; this difference in values of the second derivative is clearly exhibited in Fig. 5 by the various close bundles of the *isanomals*.

For the purpose of this interpretation of the second derivative in connection with the results of the reflection seismic survey we have made use mainly of the null-curves, but sometimes also of the signs and orders of magnitude of the associated areas with extreme values. Additional maxima and minima appear

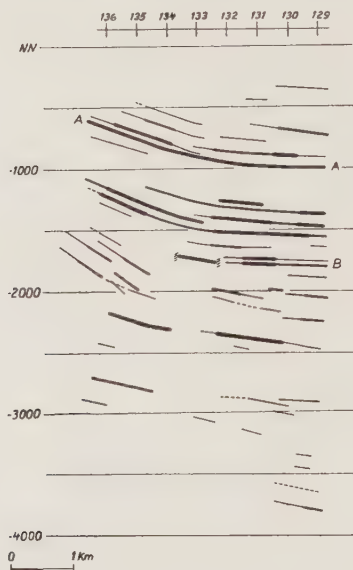


Fig. 15. Offenburg — Reflexion Seismic Profile VII.

in Fig. 5, whose examination may well be omitted here: firstly, they are easily explained qualitatively, when such an explanation is based on the effect of the mass deposits, which have been assumed here on the basis of the interpretation of the seismic and gravimetric measurements. Secondly, some maxima and minima have appeared, to which we cannot attribute any real significance in view of computational reasons as a result of the great mutual distance between the gravimeter stations and also because of unfavourable conditions for the interpolation of gravitational values. This applies for example to the two local minima in the north-east of the area under investigation.

In conclusion of the geophysical part of the present paper we may remark that the seismic investigations of the Offenburg area took place during the months June-August, while the gravimetric measurements were carried out in September 1951. Drilling was started in January 1952. The geological results,

as far as they were available by the end of the same year, will be treated in the next section.

III. GEOLOGICAL RESULTS OF BORE-HOLES

The preliminary geophysical investigations were followed by ten bore-holes; the first of them was the wildcat Offenburg 1, the others were the prospecting

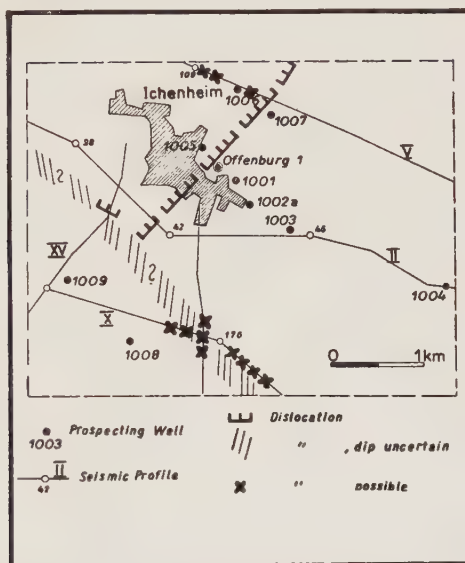


Fig. 16. Wildcat Offenburg 1 and prospecting wells SB Offenburg 1001-1009 as well as disturbances located seismically.
(Enlargement from Fig. 1 of the Ichenheim region).

wells SB—Offenburg 1001-1009. The positions of these wells relative to the seismic profiles are shown in Fig. 16.

Offenburg 1 passed the following sequence of strata: *

- 0-135 m Quaternary
- Transgression ——
- 181 m Tertiary
 - 138 m Septaria Clay (Lower Rupelian)
 - 147 m Upper Pechelbronner Schichten (Sannoisian)
- fault ——
- 181 m Striped Marls (= lower part of the Pechelbronner Schichten)
- 230 m displaced sequence of strata consisting of several repetitions of Stripel Marls and Hauptrogenstein

* Dr. h.c. K. Hoffmann (Amt für Bodenforschung, Hannover) and Dr. K. Sauer (Geologisches Landesamt, Freiburg i. Br.) assisted with the analysis of Dogger and Lias by means of determinations of the macrofossils.

- 476 m Dogger
 - 260 m Hauptrogenstein
 - 286 m Dogger delta (= beds with *Cadomites blagdeni* and *C. humphriesi*)
 - 310 m Dogger gamma (= beds with *Sonninia sowerbyi* and *Emileia sauzei*)
 - 372 m Dogger beta (= beds with *Ludwigia munchisonae* s.l.)
 - 476 m Dogger alpha (= beds with *Lioceras opalinum* s.l.)
- 608 m Lias
 - 504 m Lias zeta (beds with *Lytoceras jurense*)
 - 522 m Lias epsilon (= bituminous shales with *Posidonomya bronni*)
 - 580 m Lias delta-beta
 - 608 m Lias alpha
 - 612 m Rhaetic
 - 751 m Middle Keuper
 - 764 m Lower Keuper (= Lettenkohle)
 - 825 m Upper Muschelkalk
 - 866 m Middle Muschelkalk
 - 908 m Lower Muschelkalk
 - 956 m Upper Buntsandstein

In this section the following layers may be regarded as particularly good reflectors of seismic waves:

- 1) the Hauptrogenstein
- 2) the crystalline limestone beds of the Dogger gamma
- 3) the limestone beds of the Lias alpha
- 4) the anhydrite layers in the Middle Keuper
- 5) the Middle Muschelkalk, almost entirely composed of anhydrite
- 6) the Lower Muschelkalk
- 7) the thick and hard sandstone beds of the Upper Buntsandstein.

The following dip was measured on cores:

139,0-144,0 m	5-7°	
187,8-194,5 m	15°, 25°, 20°, 35°, 5°, 15°, 10°	
277,5-286,3 m	15°	
320,0-325,0 m	0°, 7-10°	
330,0-335,0 m	10°	
375,5-753,0 m	0°	
753,0-756,3 m	6°	
756,3-760,0 m	4°	
760,0-766,0 m	5°	
827,0-830,0 m	10°	} in anhydrite
853,5-858,5 m	20°	
869,7-872,7 m	4°	
888,9-892,0 m	4°	
910,0-913,2 m	5°	
928,2-928,9 m	20°	
931,7-938,4 m	10°	} ? cross-bedding in the Buntsandstein
944,9-950,8 m	10°	

This profile shows that Offenburg 1 passed a main zone of displacement between 147 and 230 m: In this well only some ten meters of Lower Oligocene were encountered and the underlying Dogger begins with the Hauptrogenstein. But we know that at a distance of only 2,5 km E from Offenburg 1 in SB-Offenburg 1004 the lower part of the Sannoisian already has a thickness of 350 m and that near Kehl (cf. Fig. 17), about 10 km N of Ichenheim, a boring recently encountered more than 800 m deposits of older Tertiary age below the Septaria Clay. On the other hand the Hauptrogenstein in this region has a



Fig. 17. The Rhine valley between Basel and Mannheim.

total thickness of about 60 m and is normally followed by Bathonian and even Callovian strata. These facts indicate that the displacement has an order of magnitude of at least 800 meters.

The influence of the fault, demonstrated by the dip of the layers, is noticeable to within the Dogger beta. From there down to the base of the Middle Keuper horizontal bedding exists; below this level weak but clearly recognisable dips appear again.

This observation and in particular the stratigraphic development of the Middle Keuper may indicate another disturbance in this part of the section. In contrast to the development on the slope of the northern Black Forest and in the Kraichgau (cf. Fig. 17), where this formation reaches a thickness of 270 m, only 139 m were found in Offenburg 1, the Red Marls and the Schilfsandstein not being recognisable. One might therefore be led to explain the absence of these horizons by a displacement. It should be stated however that in the Zaberner Senke W of Strasbourg the Upper Triassic is developed far more weakly than in the Kraichgau, and the Ichenheim area might correspond rather more to the

Alsatian region than to that of northern Baden. This possibility is supported by the results of some prospecting wells drilled E of Offenburg 1 with the aim of studying the connexion between the downthrown and the heaved block as well as examining the geological structure of the latter. These wells have given no indication of a larger displacement E of the main fault and therefore of the existence of a major disturbance within the Keuper formation. Perhaps the break between SB-Offenburg 1001 and 1002a manifested by the steeper dip in 1002a goes into the Keuper profile of Offenburg 1; this would mean a gap of 30-40 m.

The prospecting wells SB-Offenburg 1001-1005 yielded the following profiles:

1001:

0-117,0 m Quaternary
 ——— Transgression ———
 -206,5 m Striped Marls
 ——— Transgression ———
 -223,8 m (total depth) Callovian Clay with Macrocephalites (Dogger epsilon)

The dip is zero down to approx. 132 m, from 132 to 149 m it is 2-3°, from 149 to 160 m it varies between 10 and 34°, from 160 m to the top of the Dogger it is 2-6°, within the Dogger no dip can be observed. The change of dip manifests a minor fault within the Tertiary.

The following facts concerning this record are remarkable:

- 1) Below the Quaternary there are neither Septaria Clay nor Upper Sannoisian but only the basic beds of the Pechelbronner Schichten. The well is therefore situated completely on the heaved block E of the main fault.
- 2) In contrast to Offenburg 1 the Tertiary is underlain by a Dogger horizon younger than the Hauptrogenstein.
- 3) The base of the Quaternary lies about 20 m higher than in the case of Offenburg 1, i.e. the movement at the main fault continued up to the Quaternary.

1002a:

0-135,8 m Quaternary
 ——— Transgression ———
 -215,0 m Striped Marls
 ——— Transgression ———
 -250,0 m Upper Dogger epsilon
 -311,5 m Hauptrogenstein
 -316,7 m (total depth) beds with Cadomites blagdeni

The dip varies in the Tertiary between 0 and 12° in the Upper Dogger epsilon between 10 and 20°.

Two important results can be derived from this log: 1) The total thickness of the Hauptrogenstein is approx. 60 m and 2) there are Dogger deposits of a thickness of at least 35 m younger than the Hauptrogenstein.

1003:

0-150,0 m Quaternary
 ——— Transgression ———
 -290,0 m Striped Marls
 ——— Transgression ———
 -329,2 m Upper Dogger epsilon
 -345,6 m (total depth) Hauptrogenstein

1004:

0-160,0 m Quaternary
 ——— Transgression ———
 -495,0 m Striped Marls
 ——— Transgression ———
 -548,4 m (total depth) Dogger zeta — Upper epsilon (Microfaunistic
 determination by Dr. Fahrion)

A section through the wells Offenburg 1 and SB-Offenburg 1001-1004 proves that in the heaved block—at least in its western half—the strata dip towards E to a degree according to that observed on the cores. There seems to be no displacement between 1002a and 1004, and the two disturbed zones observed in 1004 have obviously been without any appreciable effect.

1005:

0-140,0 m Quaternary
 ——— Transgression ———
 -290,0 m Melettaschichten (Upper Rupelian)
 -320,0 m Septaria Clay (Lower Rupelian)
 -330,5 m (total depth) Upper Pechelbronner Schichten

The dip lies uniformly between 25 and 28°.

The most important finding of this well is the fact that below the Quaternary there are essentially younger strata than in Offenburg 1, about 200 m E of 1005. This boring therefore is situated in a block considerably downthrown relative to Offenburg 1 and the prospecting wells 1001-1004. It is probable that besides the main fault another minor displacement exists between Offenburg 1 and 1005 because the Septaria Clay lying in 1005 at a depth of about 300 m and dipping at 25° cannot normally be connected with that in Offenburg 1.

The direction of the main fault was determined by the wells Offenburg 1006 and 1007 which yielded the following profiles:

1006:

0-140,0 m Quaternary
 -145,0 m ? Pliocene
 ——— Transgression ———
 -162,7 m Niederrödderner Schichten (Aquitanian/Upper Chattian)

1007:

0-155,0 m Quaternary
 ——— Transgression ———
 -196,0 m Striped Marls

The main fault therefore runs NNE-SSW.

According to the results of the reflection seismic survey the heaved and the downthrown block should be bounded in the south by a NW-SE disturbance. In order to check these results the prospecting wells SB-Offenburg 1008 and 1009 were drilled.

1008:

- 0-127,0 m Quaternary
- Transgression ——
- 169,0 m Striped Marls
- Transgression ——
- 180,0 m Upper Dogger epsilon
- 230,0 m Hauptrogenstein
- 243,6 m beds with *Cadomites blagdeni*

1009:

- 0-130 m Quaternary
- 148 m ? Pliocene
- Transgression ——
- 169 m Hauptrogenstein

These records point out that both wells are located on another high block which is slightly inclined towards E. They verify the existence of the NW-SE disturbance already determined seismically.

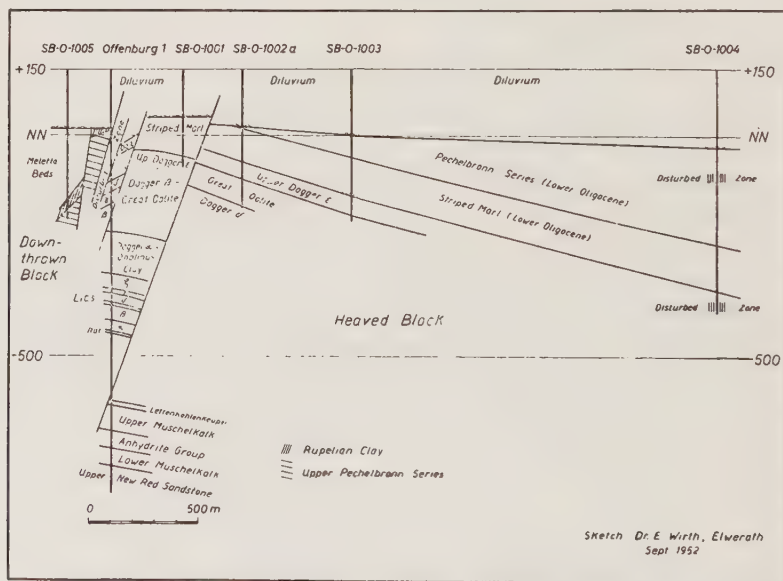


Fig. 18. Offenburg — Geological Profile (NW-SE) between SB Offenburg 1005 and 1004.

The results obtained so far are represented in the section between SB-Offenburg 1005 and 1004 (Fig. 18): In the W there is a downthrown block characterized by Tertiary deposits up to the Aquitanian, in the E there is a

heaved block which only contains lower Sannoisian beds between the Quaternary and the Dogger. In Offenburg 1 the main fault is encountered at approx. 150 m. It is accompanied both in the E and the W by a couple of minor displacements of the same sense of movement. As far as can be judged at present the zone of disturbance has a width of about 500 m. The faults dip at an angle of at least 60° towards the W. As already stated above the magnitude of the throw of the main fault can be estimated to be about 800 m.

Recapitulating we may say that this geological profile fully corroborates the geophysical findings in that area: not only is the principal disturbance between the heaved block and downthrown block given correctly, but also the dip of the layers, which causes the characteristic bulge to the north of the isogams in the central field (Fig. 4) and the conspicuous parallel displacement of the null-curve L_2 in the maps of the second derivative.

ACKNOWLEDGMENTS

Dr. G. Brinckmeier of the Gewerkschaft Elwerath, Hannover, ordered the seismic and the gravimetric surveys to be made by the Prakla, Gesellschaft für praktische Lagerstättenforschung, Hannover. He recommended the present investigation and effected permission to be given by the Gewerkschaft Elwerath for its publication. The authors wish to express to him also their sincere gratitude for his continual interest in the progress of this undertaking.

REFERENCES

- Thomas A. Elkins: "The Second Derivative Method of Gravity Interpretation". *Geophysics* XVI, 1951, 29-50.
H. M. Evjen: "The Place of the Vertical Gradient in Gravitational Interpretations". *Geophysics* I, 1936, 127-136.
O. Rosenbach: "A Contribution to the Computation of the 'Second Derivative' from Gravity Data". *Geophysics* XVIII, 1953, 894-912.

A RESISTIVITY INVESTIGATION INTO A WASHOUT FEATURE IN COAL MEASURE STRATA *

BY

G. M. HABBERJAM ** AND JOHN T. WHETTON **

ABSTRACT

The paper consists of an account of a resistivity investigation into an old river valley in Coal Measure strata. This valley denuded several of the upper coal seams leaving behind unconsolidated material and it was the purpose of the work to be described to investigate how far the extent and nature of this material could be determined by resistivity methods conducted at the surface.

As such the survey fits into a wider programme of research instigated by the National Coal Board.

The feature, which is quite well known geologically, was surveyed by conventional methods and the results obtained are discussed in relation to the above project.

Thus, the investigations succeeded in tracing the approximate centre line of the feature and in yielding some information on the nature and order of thickness of the deposits. Limitations of the method and its future application are also discussed.

INTRODUCTION

The work to be described formed one of a series of investigations which have been carried out by different bodies at the invitation of the National Coal Board, into the general problem of the possible menace to near-surface mine workings of superficial unconsolidated deposits.

The particular problem considered in this paper was concerned with a portion of the so-called "pre-glacial valley of the River Wear" in County Durham and formed one of two sites investigated by this Department in accordance with the above project.

The feature consists of a valley cut in the Coal Measure strata and denuding several of the upper coal seams. The general trend of this valley is from south to north where it finally joins the valley of the River Tyne. The floor of the valley penetrates below the present sea-level in the North and is now filled with glacial deposits; clay, gravel and sand, to a thickness of 200 feet or more in certain places.

Over part of its length, the old valley approximates to the position of the present River Wear, which however, follows a more meandering course and departs from the washout entirely before its confluence with the Tyne Valley.

* Presented at the Paris Meeting of the European Association of Exploration Geophysicists, 20/22 May, 1953.

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The area which has been investigated (See Fig. 1) lies to the south of the town of Chester-le-Street in the Wear Valley and covers a length of approximately 2 miles of the washout.

Since the investigation was concerned with testing the applicability of the resistivity method rather than a routine survey this governed the initial approach to the problem. Thus, whilst a considerable amount of information in scattered form exists, from mine workings, borings, shaft sinkings and open cast coal sites, no attempt was made to amass such information before undertaking the survey, as at a less favourable site, such extensive information would not be available.

Initial information used in planning the survey consisted of two very local groups of boreholes, one sited on the Haughs just east of Chester-le-Street and the other in the immediate vicinity of Plawsworth station. Besides this, the general trend of the Wash in a part of the area, as revealed by workings in the Hutton seam, was also utilised.

FIELD OBSERVATIONS

Preliminary observations were made at the bore hole sites above, but because of the proximity of the river at the Haughs rather cramping the investigations, the major work was situated in the Plawsworth region. The latter observations took the form of a grid of readings made with the normal configuration of four equally spaced electrodes, the spacing used being 200 ft. This grid covered a strip of ground some 1,200 ft. wide stretching from the Great North Road to the River Wear.

The result of this grid was to show high apparent resistivities in the west sinking to a low value to the east and showing a slight tendency to rise again at the River Wear. This low resistivity region showed a marked similarity to the denuded region shown on the plan of the Hutton seam workings. Since however, the general topographic trends were similar to the resistivity contours and the elevation range was of the order of 150 feet, the possibility of this effect being primarily topographical could not be overlooked.

Fortunately, to the immediate south of the low resistance area, there is a substantial hill, so that if extension of the survey to the south showed the persistence of the low resistivity zone there, a reasonable association with the Wash could be made.

The extended survey as finally carried out is shown in Fig. 1 and this includes extensions to the south, east and north of the original survey.

This extension of the survey was carried out in three discrete stages to form some conception of the merits of covering the ground in different ways. Thus that portion of the area south of the line QQ' in Fig. 1 which includes the previous work round Plawsworth, was entirely gridded using a N-S direction for the electrode lines at a station density of 460 readings/sq. mile. The rigid direction of electrode line was discontinued in the north and spot readings were

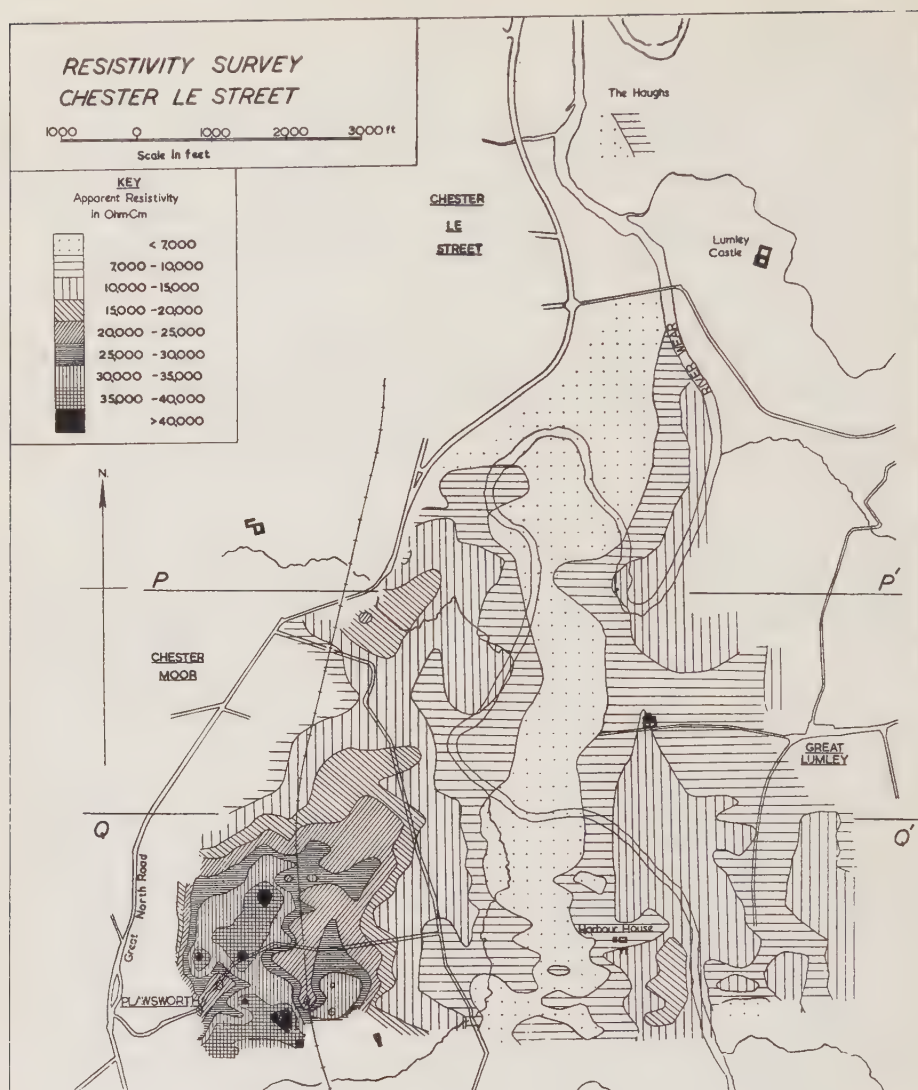


Fig. 1.

made instead of the grid. The area between PP' and QQ' was covered at a low station density of 90/sq. mile and north of the line PP' a higher density of approximately 250/sq. mile was employed.

The major objection to gridding in work of this scale is the presence of crops which may entirely stop work and delay completion. Spot reading even at a density of 250/sq. mile covers ground more rapidly and by taking readings

by field sides, most of the obstacles may be overcome. Coverage at 90/sq. mile is, of course, very much more rapid, but the correspondingly larger interpolation distances will tend to make this inadequate where resistivities are rapidly changing.

The southern portion of our area was selected for more intensive investigation and a map constructed of apparent resistivities using an electrode spacing of 50 ft. so as to obtain information of immediate surface effects. This information was further supplemented by a line of expanding electrode probes extending across the region from west to east. Two probes were also sited in the low resistivity region where it extended northwards.

RESULTS OBTAINED

Contours of apparent resistivities at 200 ft. spacing are shown in Fig. 1 at intervals of 5,000 ohm. cm. and an additional contour at 7,000 ohm. cm. has been included to define more clearly the central low resistivity region.

This central feature follows the direction of the old Wash and may be compared with the position of the denuded region of the Hutton seam and the assumed centre line as shown on the Geological map of 1870 (See Fig. 2). It will be seen that the feature persists south of Harbour House, where it passes straight through a hill and this suggests that the feature is not due to present topography nor to alluvium of the present river. For closer consideration the line of minimum resistivity is shown on Fig. 2 and it is of some interest to compare this with the fault pattern and dips of the area. The dip arrows shown have been determined from contours of the underground workings on the east side of the area and do not relate to individual determinations.

Comparing this pattern, there is a tendency for the minimum resistivity line to bulge down dip whilst retaining its general south to north course, whilst in the north, where the dip is also to the north, the centre line becomes quite straight after a preliminary meander.

The assumed straight line course of the Wash is highly conjectural and dates from the work of Wood and Boyd (1863). More recent work to the south of the area, by Hopkins and Hindson shows the Wash to have a more sinuous form and the northern part of their predicted centre line is shown in the figure. The area of overlap with this work is unfortunately very limited and does not permit a good comparison. It will be noticed, however, that whilst the overlap itself shows a considerable divergence between the line of minimum reading and this centre line, the former swings into the approximate position of the extension of the latter line.

Any precise correlation of minimum reading with greatest depth would, of course, assume very simple conditions and such cannot be expected to hold. The numerous faults of the area can be expected to result in the Coal Measures presenting material of different resistivities at the base of the Wash and further there may be considerable variations in the washout material itself. In this

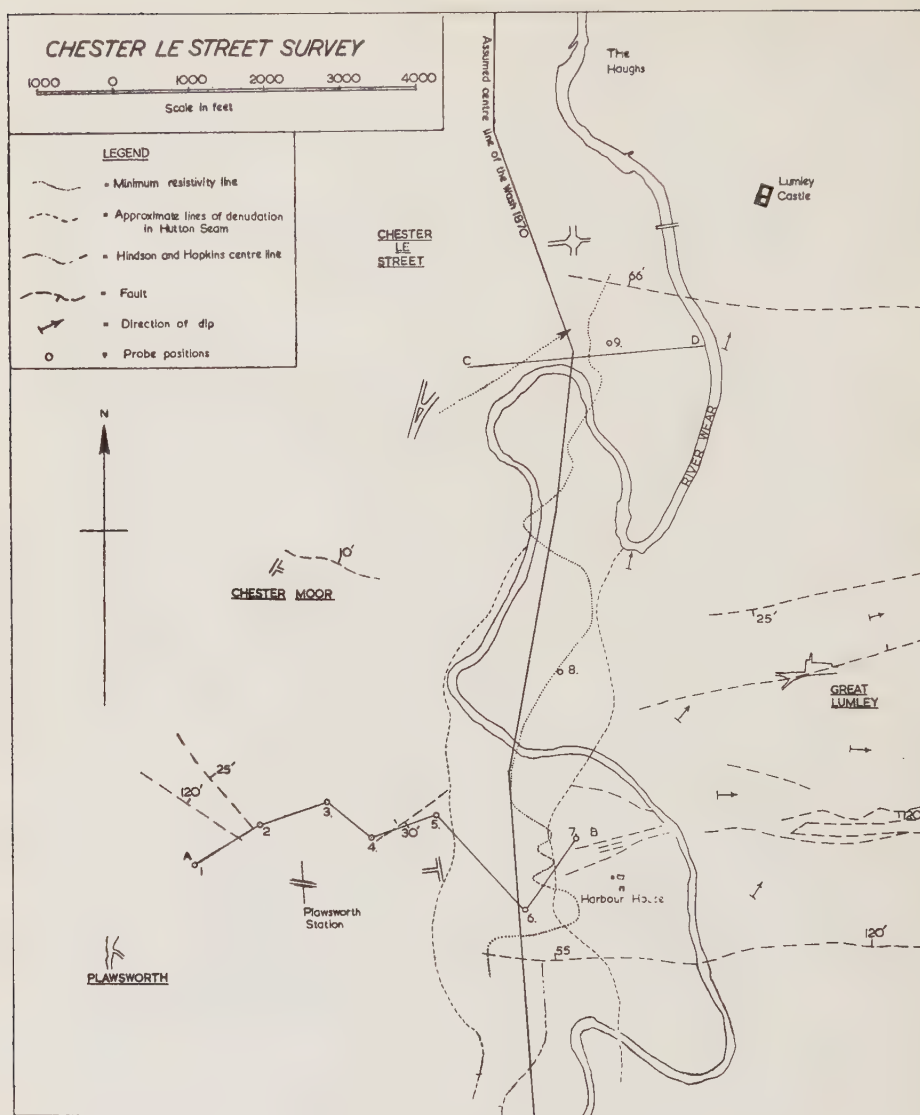


Fig. 2.

particular problem, these effects are probably of greater significance than any topographic distortion of the minimum resistivity line since there is apparently no direct association with the latter.

In the extreme S.E. portion of the survey, the Wash is absent and as this region is considerably faulted it gives some indication of the general range of apparent resistivities. This range appears to be limited in the main between

10,000 and 20,000 ohm. cm. and this may help to account for the centre line correspondence shown, especially in the northern part of the area where the centre line follows the flood plain of the river and no topographic effect will enter.

The possibility of variation of the material composing the Wash is, however, much more serious, and whilst apparent resistivities are low along the centre line 6,000 ohm. cm., in the S.W. they range up to 40,000 ohm. cm. or more. Although these high resistivities are mainly concentrated in S.W. they raise the possibility that in certain circumstances there may be no available contrast

MINIMUM RESISTIVITY LINE

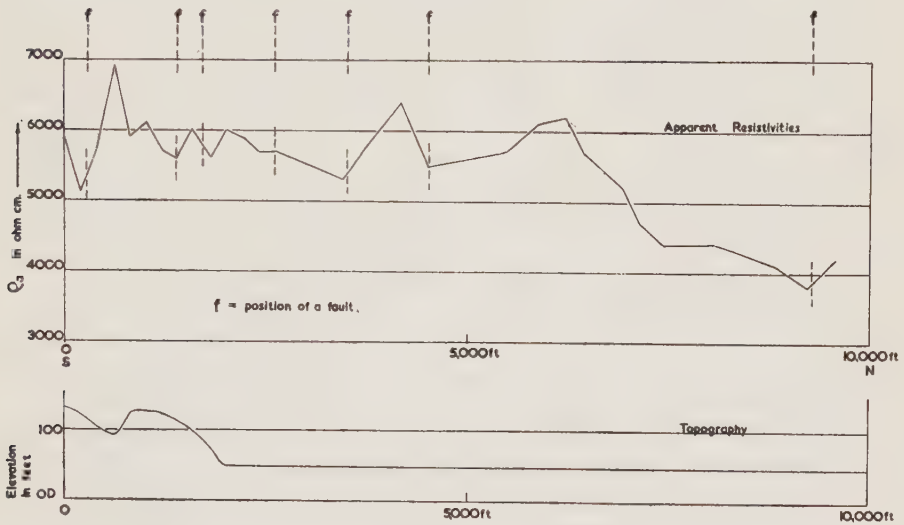


Fig. 3.

between washout material and Coal Measures in which case the method will break down.

The likelihood of changes in the material within the Wash causing variations between minimum reading and centre line would appear from the above to be greater in the south of our area, which also includes the major faulted region.

In Fig. 3 the minimum apparent resistivities are shown projected on to a north-south line together with the corresponding elevations. This figure shows an average value of about 5,900 ohm. cm. in the south which is maintained until in the northern part of the area it falls rapidly to a value nearer 4,200 ohm. cm. This fall might suggest either an increase in the depth of the Wash or a change in the resistivity of the material. Evidence will be brought forward later which suggests that at least the greater part of the effect is due to the latter cause.

Superimposed on this general tendency are more minor fluctuations which may be partly due, at least in the central region, to inadequacy of station density. That fluctuations are as severe in the region of highest density in the south may indicate that this in itself is not the main cause. In order to check the effect of changes in resistivities of material below the Wash the positions where faults, shown on the plan of underground workings, or the immediate extension of neighbouring faults, cross the minimum resistivity line, have been marked on the section.

The fault positions do appear to be related to the resistivity curve in that practically all are associated with low readings and may correspond to local water accumulations in the fault planes. The general line of the faults is not discernible in the other areas covered by the Wash, but this may result from the much more pronounced effects of the Wash itself.

Returning to the plan of the minimum reading line; at its northern extremity it suffers a minor deflection to the north east. Leading up to this region from the south west is a second line of low reading and this might suggest a tributary washout approaching from this side. Such a tributary has in fact been located further to the south west at Chester Moor, so that this may form its approximate line of confluence with the main feature. Unfortunately the survey is rather restricted in this region by the town of Chester-le-Street itself, so that a fuller investigation could not be made.

As already pointed out, the southern part of the area was also the site of a further survey using an electrode spacing of 50 ft. This comprised, in all, some 200 readings and a contour plan at 10,000 ohm. cm. intervals is shown in Fig. 4. The purpose of this survey was to test the persistence of the previous features (shown in Fig. 1) towards the surface.

The main low resistivity area has now broadened considerably and overlaps considerably to the east. Since the spacing is so small, part of this effect may be due to boulder clay cover on the Coal Measures, although even on the 200 ft. spacing, the contrast between the Wash and the latter is not great.

In the west of the area, the high resistivity material corresponds approximately to the equivalent feature on the 200 ft. spacing map although tending to higher values in the extreme S.W. Thus, if we assign the apparent resistivity changes mainly to changes in the constituent materials of the Wash, then the results in this area suggest high resistivity material in the west and low in the east, with this second material tending to overlap the first.

Returning to the low resistivity area, a major high of limited extent (C) is shown in the south where on the previous survey the low resistivity channel was located. This high corresponds to part of the hill south of Harbour House, mentioned earlier and is further evidence that the previous low resistivity channel is not a topographic feature.

East of Harbour House the area is free from the Wash according to geological evidence although, as pointed out above, there may be considerable

boulder clay cover. This is confirmed to some extent by the tendency of the resistivity contours to swing towards the strike line of the Coal Measure strata (here approximately NW-SE). Further evidence lies in the low area crossing the highs A and B and the fact that the line linking this region with the northern extent of the highs on either side corresponds approximately to a major fault.

To gain information of the section in the south, a line of expanding electrode probes ranging in separation up to 500 ft. was made and the results obtained

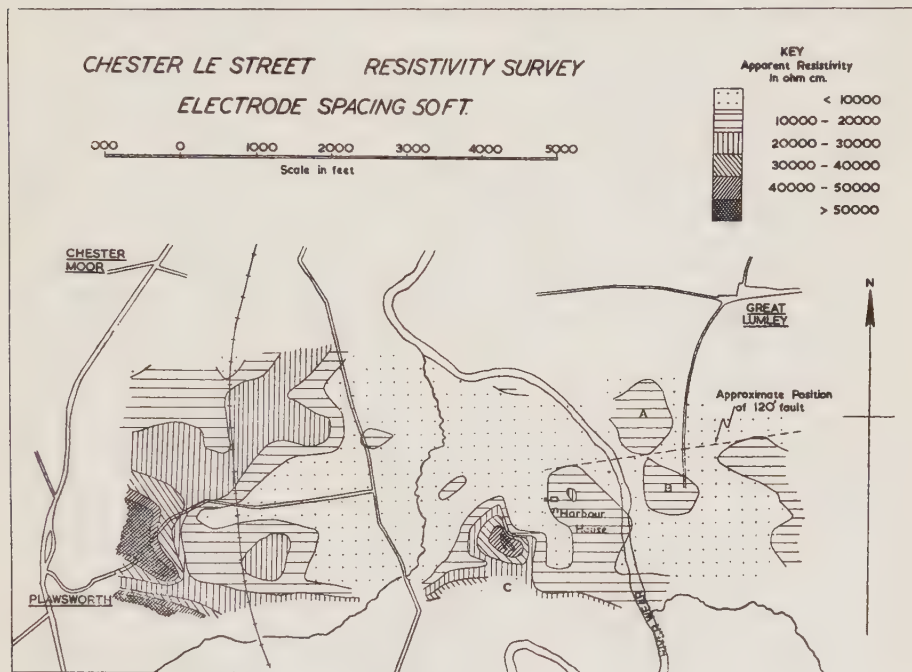


Fig. 4

are shown in Fig. 5. These again show that there is a belt of high resistivity material on the Plawsworth side (see Fig. 2 for probe positions). The probes are all of a three-layer character and in regions of rapidly varying resistivities depth estimates can be expected to be poor. Perhaps the most interesting feature of the probes is the complete change of character as the low resistivity region is approached, indicating a change in the constituents of the Wash. In order to obtain the relation between these constituents, depth interpretations were made using the probes themselves together with the intermediate 200 ft. spacing values. The method used was the logarithmic method due to Roman. This being strictly a two-layer method, and for the reason above, the estimates are very approximate and must be considered as qualitative rather than quantitative.

RESISTIVITY PROBE RESULTS

a = electrode spacing in feet

ρ_a = apparent resistivity in units of one thousand ohm cm.

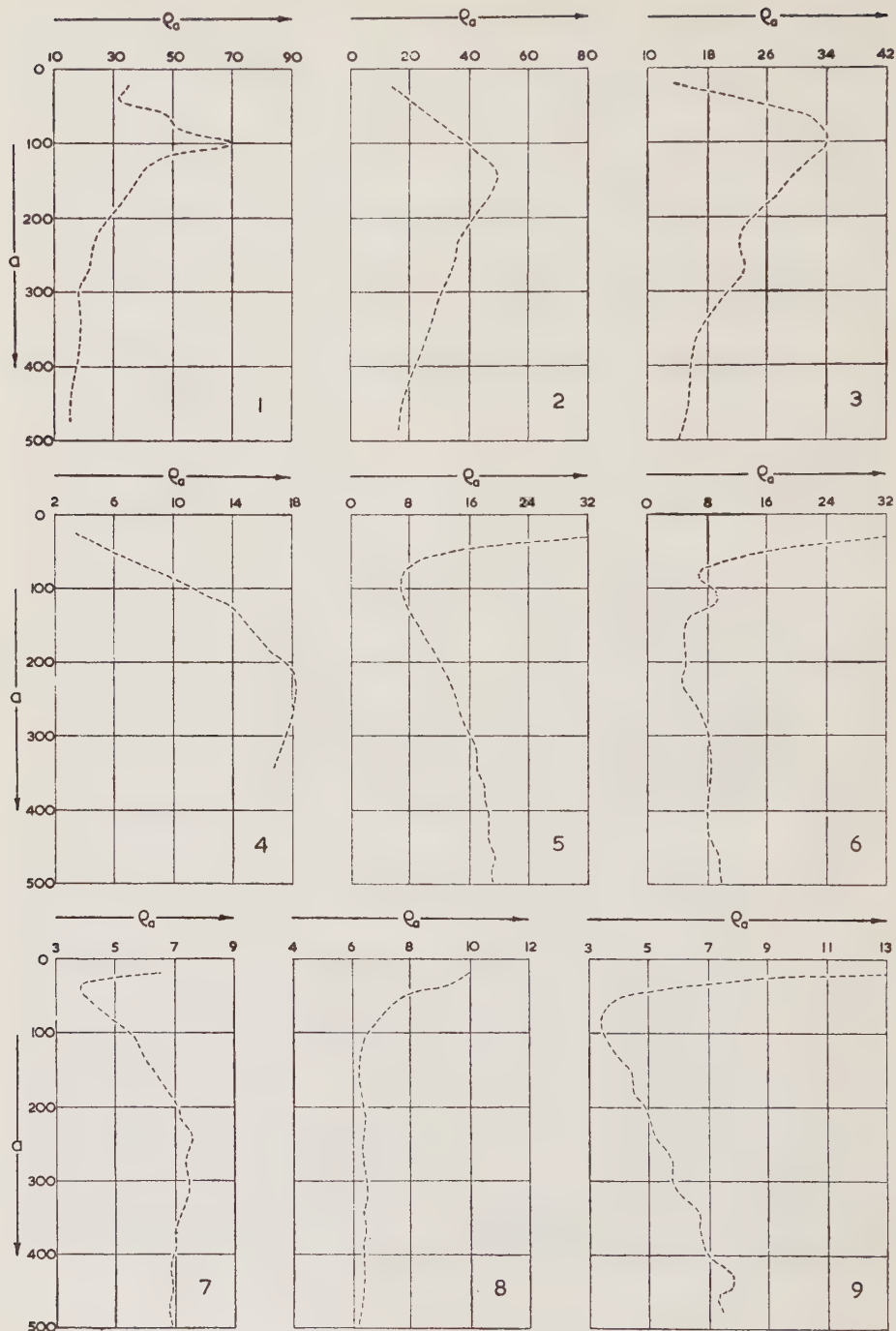
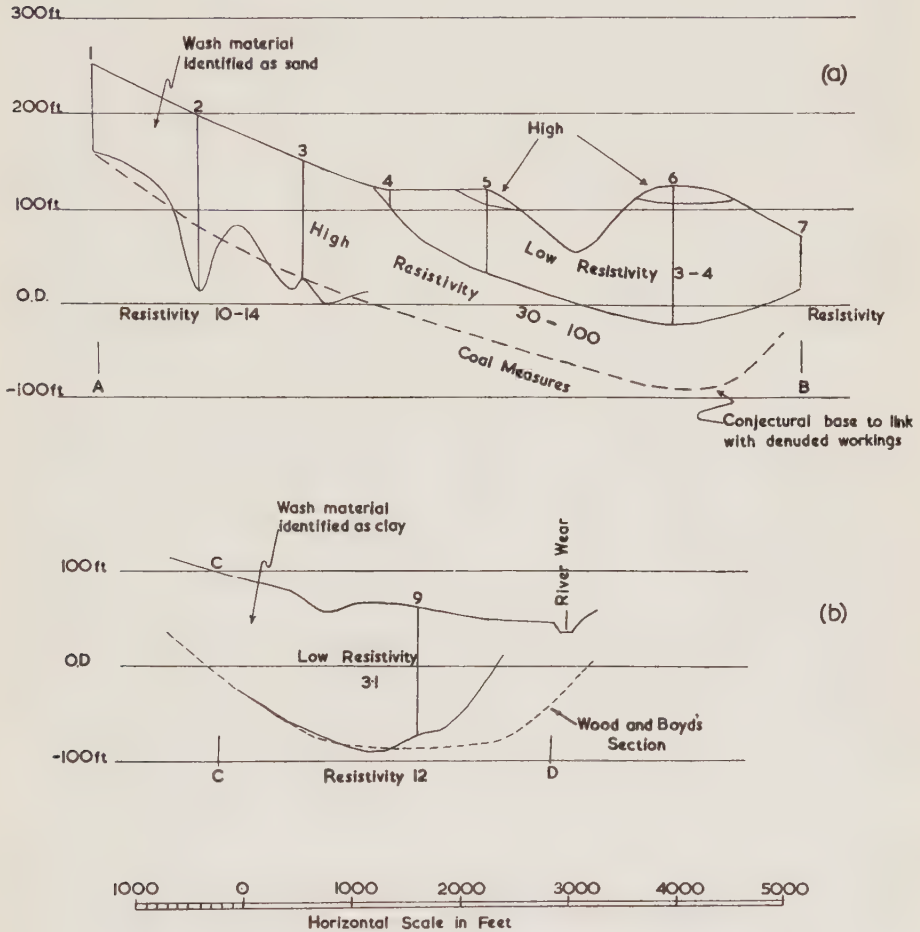


Fig. 5.

CONJECTURAL SECTIONS OF THE WASH



Resistivity ranges are given in units of one thousand ohm cm.

Full lines refer to horizons based on electrical evidence

Fig. 6.

These estimates are summarised in the tentative section shown in Fig. 6(a). Thus, in the high resistivity region on the west side the thickness of this component is of the order of 100 ft. and tending to increase slightly to the east. Close to this region is the group of bore holes at Plawsworth which confirm this order of depth and the slope to the east. All these bore holes associate the material with sand and gravel, although there is generally a shallow capping of boulder clay. Reaching Probe 4 the second constituent starts to enter with a low resistivity (2,200 ohm. cm.) at the surface. Because of the limited maximum length of the probes this boundary now becomes the lower one on the curves obtained for the probes on the eastern side. From the plan of underground workings, the Wash extends to a depth of about —80 ft. A.O.D. at the eastern line of denudation of the Hutton seam. Probes 5 and 6 do not suggest that the low resistivity material extends to the base of the Wash and the resistivities immediately below are of the order of 40,000 ohm. cm. and thus more comparable with the high resistance wash in the west than to the Coal Measures. Further at the most easterly point at which the depth of this high resistivity material has been located electrically, it appears to be plunging under the low resistivity cover.

The dotted line shown is the conjectural extension of the geophysical horizon to link up with the geological evidence as revealed by underground workings. The resistivity of material below the Wash at Probe 7 falls to 10,000 ohm. cm. so that this may be associated with Coal Measure strata again. If this be so, then we have to postulate a steep rise in the lower material on the eastern edge.

The probe evidence thus gives the section of the Wash as composed of two different components in this area with low resistivity material overlying high resistivity material. Further in the central region the low resistivity material has in turn a capping of higher resistivity at an elevation of about 100 ft. O.D. This helps to account for the complexities of the low resistivity region in the south of Fig. 1. It now appears that this is to be associated with two major effects:

- (i) The rapid thinning of high resistivity material in the east, and
- (ii) The low resistivity component.

From this it would appear that at least in this southern region the line of minimum resistivity will not correspond exactly with the line of maximum depth of the Wash. The relation between the two lines will be governed rather by the conformability of the two constituents.

The high resistivity constituent is identified as sandy material by boreholes and surface exposures in the area to the west and as distinct from this the low resistivity material may correspond to clay, although we have no bore hole evidence to confirm or deny this in this southern area. A characteristic blue clay is known to occur in the Wash and in sections north of the area investigated, Wood & Boyd show this material lying over sand and gravel deposits so that it may be that a similar order occurs in this area.

The shape of the section obtained compares with that found about one mile to the south by Hindson and Hopkins although those authors make no comment on the constitution of the Wash on this section.

Considering now the additional probes sited to the north in the low resistivity region, these tend to show that the pattern of constituents in the south is not maintained immediately to the north. Thus probe 8 shows a thin high resistivity surface layer overlying material of about 6,000 ohm. cm. resistivity. This latter figure is maintained and suggests that this material extends to the base of the Wash and that contrast with material below it is very small. This gives then a rather lower figure for Coal Measure strata in this region than observed elsewhere, but this may arise because the material is at depth and no strict comparison can be made with surface apparent resistivities. In Fig. 1 it will be seen that west of this probe the high resistivity region is very much reduced and this may help to account for the lower resistivity of the washout material at this probe, the Wash here possibly corresponding to more mixed constituents, the layered character being no longer apparent.

To the north of this probe and still in the low resistivity region Probe 9 was sited. This is again of three-layer form and the depth estimate to the lower discontinuity was of the order of 134 ft. With an upper resistivity of 3,100 ohm. cm. and a contrast of +0.6 this gave a resistivity of approximately 12,000 ohm. cm. for material below this depth. This latter figure may as a result correspond again to Coal Measures so that this depth *may* represent the depth of the Wash at this point.

It would thus appear that in moving north from Probe 8 the resistivity of washout material has decreased whilst that of the material below the Wash has increased, the net result producing a favourable contrast at Probe 9 whilst contrast was lacking at Probe 8. The steep fall in apparent resistivities shown on the centre line (Fig. 3) is now primarily associated with the change in resistivity of the Wash rather than to depth variations. It is also of interest to note that this washout resistivity is of the same order as the upper constituent of the Wash found on the section to the south and may again be associated with a predominately clay constitution.

As well as the disappearance of the lower high resistivity component observed in the south, the westerly high apparent resistivities observed in the latter region have also disappeared, although this may be partly due to the restriction of the surveyed area in the north. These circumstances suggest that the low resistivity component of the Wash may be the only one present in the north.

In their early paper Wood and Boyd showed a section of the Wash in this area along the line CD in Fig. 2. Using the information in Probe 9 together with the observed apparent resistivities along this line, and assuming the resistivity values obtained from the probe to hold along this line of section,

a depth profile has been constructed. This profile is compared with that of Wood and Boyd in Fig. 6(b).

In this figure, it may be seen that depth agreement is quite good on the Western side tending to confirm these somewhat simpler conditions and a neighbouring borehole also confirms a predominantly clay constitution on this side. In the east, however, whilst the profile shows a steeper bank, confirmed by Wood and Boyd, the position according to these latter investigators, is some 800 ft. further to the east.

The electrical profile has however been constructed on only one probe and the effect may be due to changes in constitution of the Wash leading to somewhat higher resistivities in the east. Such a state of affairs would reduce the favourable contrast but with the lack of further probes to the east little can be added.

SUMMARY

Of the boreholes included in the survey those used, that is, the group around Plawsworth, were unfortunately situated in that they did not form suitable sites for the location of electrical probes. The survey has thus been dependent mainly on the electrical observations themselves and on information obtained from underground workings.

Observations made at constant electrode separations, of themselves, revealed a low resistivity channel whose course closely followed the assumed centre line of the washout and also showed a possible tributary feature for which there is some geological support.

From knowledge of the approximate extent of the Wash, it was observed that apparent resistivities within the pre-glacial valley completely overlap the range of resistivities observed in the Coal Measures themselves. It therefore follows that possibilities exist of untraceable regions of the feature, so that, in any general application, success of the method is not assured.

Again, with the guidance of geology the observations revealed information on the washout structure suggesting in the south low resistivity material (possibly clay) resting on sand; the latter constituent being proved by bore holes on the west side. Two tentative sections have been constructed both of which confirm a steeper eastern side to the pre-glacial valley.

The minimum resistivity line has been considered at some length in relation to both the assumed centre line and to the faults of the area. The sections obtained, however, tend to show that little justification exists for modifying the assumed centre line to conform to that of minimum resistivity as the structure of the Wash and lower resistivity variations may well account for the discrepancies between the two.

Certain depth estimates have been made in order to construct the previous sections but no great accuracy claims were made as no satisfactory calibration against known bore holes was possible.

From the investigations described we feel that resistivity investigations can assist considerably in elucidating the nature and position of unconsolidated deposits of this type and that closely integrated with known geology may provide a more satisfactory basis for the siting of bore holes. Worked in association with such a drilling programme, it should be possible to form better depth estimates and where these estimates refer to the operative horizon, to interpolate between boreholes. Where this may not be possible, that is, where the constitution of the feature is changing considerably, the electrical survey will provide some information of this circumstance with its consequent bearing on safety.

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REFERENCES

- N. Wood and E. F. Boyd: On a Wash or Drift through a Portion of the Coal-Field of Durham. *Trans. North of Eng. Inst. Min. Eng.* Vol. 13, pp. 69-85, 1863-4.
- G. Hindson and W. Hopkins: The Relationship of the Coal Measures to the "Wash" between Shincliffe Bridge and Harbourhouse Park, Co. Durham. *Trans. Inst. Min. Eng.* Vol. 107, pp. 105-118. 1947.

CERTITUDE DES RÉSULTATS DE LA PROSPECTION GÉOPHYSIQUE *

(ACCURACY OF THE RESULTS OF GEOPHYSICAL PROSPECTING)

BY

M. MATSCHINSKI **

ABSTRACT

The writer classifies problems of geophysical interpretation. He distinguishes four fundamental problems and indicates the methods of solving them. Among these methods he refers to classical methods and methods based on the writer's theoretical work.

The geophysical examples are developed, as well as the very simple numerical examples. Methods of enumeration are also referred to. The whole object is to show that the practical application of the geophysical methods suggested will not give prospectors any difficulty.

On sait quel développement a pris dans les récentes techniques l'investigation de l'intérieur de notre Globe en général et tout spécialement des richesses du sous-sol.

Les sciences pures, à l'instar de la technique, appliquent des méthodes nombreuses et diverses pour pénétrer au cœur même du problème par l'imagination, là où les moyens matériels ne sauraient atteindre.

Le problème que je voudrais poser ici, et qui, à ma connaissance, n'a pas été posé dans toute son ampleur jusqu'à ce jour, est le problème de la certitude à conférer aux résultats de ces investigations, que l'on peut définir par le terme de „recherches indirectes”.

Il est évidemment superflu de parler de la certitude des résultats des „recherches directes”; lorsque par un forage nous obtenons un échantillon d'une roche donnée, la certitude est complète. Soulignons que dans ce qui suit je n'envisage pas la certitude philosophique, dite spéculative, mais seulement la certitude scientifique et technique. Juger de nos possibilités de perception serait sortir du domaine de la géophysique, l'objet vu ou touché est, pour la science, définitif.

Malheureusement les possibilités d'investigation au moyen de forages dans l'intérieur de notre Globe sont très faibles: quelques milliers de mètres de profondeur atteints à grand peine, et avec des frais considérables par les forages, ne sont rien à côté des six millions de mètres du rayon terrestre. Cela du point

* Presented at the Paris Meeting of the European Association of Exploration Geophysicists, 20/22 May 1953.

** Centre National de la Recherche Scientifique, Paris.

de vue de la géophysique théorique. Mais aussi dans les recherches de géophysique des ingénieurs on se tourne vers la méthode indirecte, car il est, bien entendu, économiquement impossible de faire beaucoup de forages. On juge alors des processus et de la nature des roches gisant dans les profondeurs, sans les avoir ni vues ni touchées et sans avoir pu recourir à l'analyse chimique. On ne les juge que grâce au faible concours des propriétés physiques, propriétés hypothétiques et indirectes.

Aussi bizarre que cela puisse sembler, le problème de l'évaluation des certitudes apportées par les méthodes indirectes dans le domaine de la géophysique n'a pas été élaboré jusqu'ici, comme je l'ai déjà dit.

Théoriquement ce n'est pas impossible, ni même difficile: les méthodes de statistique et la théorie des probabilités sont maintenant à tel point développées qu'on peut les appliquer en principe à des problèmes bien plus vagues que ceux de la géophysique. Ainsi l'on évalue les probabilités des incendies ou des accidents routiers, et la certitude en découlant permet aux sociétés d'assurance de fonctionner avec des bénéfices normaux. Par cet exemple je voudrais souligner qu'il ne s'agit pas seulement de traiter de la certitude à des fins théoriques, mais aussi en ayant en vue des buts d'ordre pratique. Ce qui est déjà vérifié dans le domaine des assurances ne saurait être impossible en géophysique.

Mais la réalisation pratique en géophysique est rendue malaisée faute de développement de certaines branches de la théorie des probabilités et de la statistique. Tout compte fait il s'agit d'élaborer une méthode de détermination de la vraisemblance (certitude) d'une hypothèse, en partant de données d'observation.

On a déjà défini de telles méthodes dans le domaine des sciences biologiques et économiques. Il suffit de rappeler les noms de C. PEARSON et R. FISHER. Cependant dans le domaine des sciences physiques, en géophysique notamment, il y a des dissemblances qui rendent impossible l'application des conceptions de statistique biologique ou autres.

C'est pourquoi dans les Comptes Rendus de l'Académie des Sciences* j'ai tenté d'établir une théorie d'évaluation de la certitude des hypothèses en vue des applications physiques et spécialement géophysiques. Dans notre mémoire „Prospection géophysique et certitude d'interprétation de ses données” — *Geofisica pura e applicata*, Vol. 27 (1954) (sous presse), j'ai exposé, à l'aide d'exemples choisis, les méthodes de calcul pratique devant servir à l'évaluation de cette certitude. Ici, sans entrer dans la description des principes théoriques** ni même dans les détails des calculs pratiques, je chercherai à faire comprendre le concept fondamental et les idées directrices de cette recherche. Essayons de

* Sur les probabilités inverses, C. R. Acad. Sci. Paris, t. 231, p. 1282, 1950.

Sur la probabilité des hypothèses, Ibid., t. 234, p. 1428, 1952.

Sur la probabilité de l'hypothèse de périodicité, Ibid., t. 235, p. 14, 1952.

Sur les compositions applicables à l'estimation de la probabilité d'une hypothèse, Ibid., t. 236, p. 1849, 1953.

** Ces principes sont schématiquement exposés dans le „Supplément” — voir p. 48.

montrer par un exemple concret le fil général qui doit nous guider dans une telle investigation. Considérons un miroir sismique, c'est-à-dire les ondes issues



Fig. 1

d'une explosion provoquée intentionnellement (voir fig. 1), qui après réflexion et réfraction, reviennent à la surface terrestre où elles sont enregistrées par nos appareils. On peut faire des hypothèses diverses sur la disposition des couches profondes. Si parmi ces hypothèses plusieurs se trouvent en contradiction avec nos mesures, il en est bien d'autres qui s'y accordent de manière plus ou moins satisfaisante. La certitude de l'hypothèse choisie n'est alors que la probabilité relative de cette hypothèse par rapport à toutes celles qui concordent plus ou moins avec les résultats enregistrés.

Pour simplifier encore le problème, imaginons qu'il n'y ait qu'une seule hypothèse s'accordant avec nos mesures. Afin d'éviter tout malentendu on doit préciser le terme d'„hypothèse” dans son acception présente. Admettons que l'hypothèse en question est celle d'une seule couche plane inclinée (fig. 2). Mais, même dans ce cas, il ne s'agit pas à proprement parler d'une hypothèse unique, mais de plusieurs: l'existence de chaque couche à un angle d'inclinaison donné est par elle-même une hypothèse différente. On s'aperçoit alors qu'une hypothèse en apparence unique implique de nombreuses hypothèses. La couche plane inclinée est représentée sur la fig. 2 et les ondes réfractées-réfléchies arrivées aux sismomètres 1, 2, 3 ... etc. sur la fig. 3. Dans le



Fig. 2

cas idéal (roches très homogènes, sans accidents, sol et couches bien délimités), le retard des ondes sera exactement proportionnel aux distances parcourues.



Fig. 3

Pratiquement, ces conditions ne sont jamais réalisées, et les difficultés résident dans l'ignorance où nous sommes, de pouvoir discerner quelle partie d'irrégularité (fig. 3) doit être expliquée par les déviations accidentelles et quelle partie doit nous amener à changer l'hypothèse choisie. Habituellement on procède en sens contraire; on ne

part pas d'une hypothèse arbitraire, mais l'on essaie d'imaginer une hypothèse présentant les moindres déviations des données observées. Il est superflu d'expliquer qu'entre deux hypothèses présentant, l'une de plus petites déviations (fig. 4a), l'autre de plus grandes (fig. 4b), on choisit toujours la première comme étant la plus vraisemblable. C'est presque un lieu commun, et je ne m'y suis arrêté que pour mieux faire comprendre ce qui suit.

Imaginons un autre groupe d'observations qui suscitent les deux mêmes hypothèses que le groupe précédent (fig. 5a et 5b).

Ici également on s'aperçoit que la première hypothèse est la plus vraisem-

blable, mais, de plus que la coïncidence de cette première hypothèse avec les faits est plus incertaine que dans le premier exemple. Toutefois les expressions „plus” ou „moins” ne sont que des mots vagues, et la science doit les remplacer par des estimations numériques.

Ces estimations numériques ne doivent pas être seulement un jeu de l'esprit, mais avoir des conséquences pratiques, conséquences pratiques dans le sens même dans lequel les sociétés d'assurance exploitent les données numériques de la statistique dans le domaine de leurs opérations. Bien entendu le fonction-



Fig. 4



Fig. 5

nement d'une société d'assurances est concevable sans l'application de données statistiques. Mais un tel fonctionnement serait bien incertain d'un point de vue économique et nulle société moderne ne se priverait de l'aide que nous apporte la théorie des probabilités.

Le même état d'esprit doit s'instaurer dans le domaine de la géophysique. Chaque investigation, de valeur tant purement théorique que technique, doit être accompagnée d'une estimation numérique sur la certitude des résultats acquis. Cette estimation sera également utile pour la science et pour la technique. À première vue elle évitera beaucoup d'hypothèses gratuites sur l'intérieur du Globe. L'expression „hypothèse la plus vraisemblable” nous influence souvent au point de faire naître des opinions peu fondées. Par exemple entre des hypothèses ayant 96 %, 3 %, et 1 % de certitude, la première est la plus vraisemblable, et vraiment très vraisemblable. Mais entre 40 hypothèses avec 4 % pour la première probabilité, 3 % de la seconde à la 19ème, 2 % de la 20ème à la quarantième, la première hypothèse est aussi la plus vraisemblable, mais, entre nous, très peu vraisemblable. Cet exemple extrême nous montre à quel point le mot „vraisemblable” est vague en tant qu'estimation.

De plus, il existe encore une difficulté de principe. Nous avons parlé plus haut des hypothèses plus ou moins proches des observations. Mais qu'est ce qu'une hypothèse proche ou une hypothèse éloignée? Si l'hypothèse ne devait coïncider avec les observations qu'en un seul point, il ne serait pas difficile d'avoir une opinion, en estimant le degré de coïncidence à l'aide de la valeur de la „distance” entre ce point donné et l'hypothèse. Mais ce n'est jamais le fait. Au contraire, on a, en effet beaucoup de données d'observation (voir fig. 4 et 5), et on a, par conséquent, beaucoup de „distances” ($A'A'$, $A''A''$, etc.) entre l'hypothèse et les faits. C'est presque toujours le fait que, si pour une hypothèse nous jugeons les „distances” d'un groupe petites et d'un autre

grandes, pour l'autre hypothèse le premier groupe contiendra les „distances” grandes et le second groupe les „distances” petites.

Il existe deux issues à cette difficulté. La première, déjà longtemps connue, est l'introduction d'une fonction des „distances” mentionnées. Cette „fonction d'estimation” Φ est supposée caractéristique dans le sens que sa valeur plus petite indique l'hypothèse plus „proche”. Naturellement, l'introduction de telles fonctions caractéristiques est, dans la plupart des cas, indispensable. Cependant il n'est pas facile, ni de choisir pour elles des formes inattaquables, ni de déterminer les probabilités qui leur correspondent. Habituellement on prend pour cette estimation une moyenne quadratique, ce qui est très commode et ce qui peut être fondé d'une manière suffisante. Mais, même si ce choix est accepté,

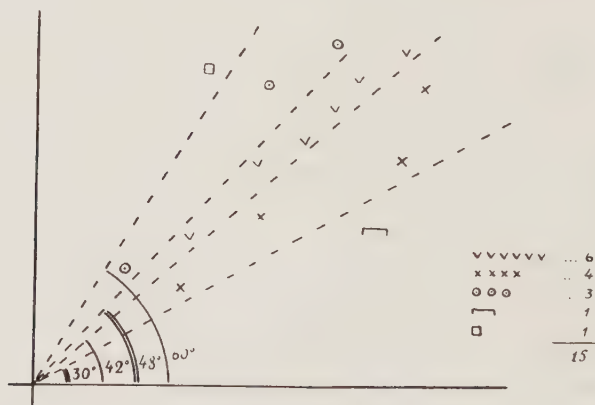


Fig. 6

les difficultés de fond ne sont pas encore résolues. Sans entrer dans ces difficultés [voir p.e. notre note — loc. cit. t. 236, p. 1849 (1953)], soulignons ici seulement que la manière suivant laquelle on résout ces difficultés dépend sensiblement du caractère des applications éventuelles; pour l'application aux sciences biologiques et économiques, les simples suppositions suffisent qui ne sont pas cependant applicables dans le domaine des sciences physiques et spécialement en géophysique.

Mentionnons aussi la deuxième méthode pour supprimer l'obstacle de principe lié à l'acceptation d'une hypothèse comme „proche” ou „éloignée”. Cette méthode est difficilement praticable parce qu'elle exige des observations très nombreuses. Mais cette méthode est importante parce qu'elle fait apparaître très clairement les difficultés capitales qui se rencontrent toujours dans toutes les investigations de ce genre.

Pour expliquer le principe de cette méthode, considérons la fig. 6. Les résultats d'observation sont indiqués sur cette figure par les signes différant selon l'hypothèse dont les conséquences sont les plus „proches” du résultat expérimental donné. Ainsi les données d'observation qui sont plus proches de l'hypo-

thèse I sont marquées par le signe $\times$ celles qui correspondent à l'hypothèse II par le signe $\odot$, etc. De cette manière on évite de poser la question comment on doit comparer les séries des „distances”. Enfin pour juger de quelle hypothèse le résultat considéré est plus proche, il n'est pas nécessaire de construire les fonctions caractéristiques. Il suffit également pour départager d'après cette condition les points parmi les hypothèses, de les énumérer et de les compter. Les nombres relatifs de ces points (de ces observations) représentent la vraisemblance relative des hypothèses. Le détail est clair d'après le fig. 6.

D'une manière tout-à-fait analogue on peut traiter la question du point de vue purement géophysique et départager tout le plan en parties correspondant aux différents résultats des observations. Après, on classe ces parties selon les données hypothétiques (les hypothèses) qui se trouvent dans ces parties du plan (ou, le cas échéant, de l'espace). Enfin, il ne reste qu'à compter; les chiffres relatifs nous donnent les vraisemblables.

Mais il ne faut pas penser que cette méthode énumérative peut se passer des hypothèses de base. Au contraire, l'exemple des paradoxes de *Bertrand* nous montre que l'absence apparente d'hypothèse en probabilités géométriques n'est souvent que la présence d'hypothèses implicites. Ainsi dans notre cas la répartition du plan entre les unités hypothétiques est déjà une hypothèse sur la valeur probabiliste, égale ou inégale, de ces „unités”, de ces parties. En ce qui concerne le premier exemple de la méthode énumérative cette remarque est valable pour des raisons encore plus fortes.

On peut enfin traiter la répartition du plan de la fig. 6 en „unités” hypothétiques comme un procédé simple illustrant un choix spécial de la fonction Φ , fonction à la dérivée non-continue: Φ est égale à une constante donnée pour certaines distances, et égale à zéro pour toutes les autres. Alors de ce point de vue la méthode géométrique n'est que le cas spécial de la méthode générale, introduction d'une fonction arbitraire Φ .

Toutefois cette méthode géométrique est très commode pour faire comprendre comment on peut aborder le problème en question du point de vue pratique. Au contraire, du point de vue théorique le procédé géométrique n'apporte aucune amélioration; toutes les difficultés de principe restent les mêmes [loc. cit. t. 236, p. 1849 (1953)]. On résout ces difficultés de l'une des deux manières suivantes: on recourt soit au principe général de l'uniformité [voir loc. cit. t. 231, p. 1282 (1952)], soit à une hypothèse *ad hoc* et on la justifie par les observations ultérieures.

Sans entrer dans le détail purement mathématique, considérons à titre d'exemple quelques cas numériques *. Dans ce qui suit les données des observations sont interprétées sous la forme de points dans le plan „profondeur” — „distance horizontale” (mais non dans le plan: „temps de parcours” — „distances” comme on l'a fait plus haut — voir les fig. 3-5). On recalcule la première forme de la deuxième (qui est immédiatement donnée) en tournant le graphique autour de O; l'angle est une fonction élémentaire de la vitesse des

* Nous les empruntons à notre note loc. cit. t. 234, p. 1192 (1952).

ondes sismiques, vitesse déterminée par expérience ou à l'aide de considérations théoriques.

Imaginons les résultats des observations représentés par la fig. 7a. Faisons l'hypothèse d'une couche plane. La profondeur d'une couche plane, déterminée par la fig. 7a est évidemment la distance a . En appliquant les méthodes expliquées on trouve: la probabilité de cette profondeur soit:

33 %	si on se permet les écarts de	2 %
69 %	" " " " " "	5 %
85 %	" " " " " "	7 %
96 %	" " " " " "	10 %

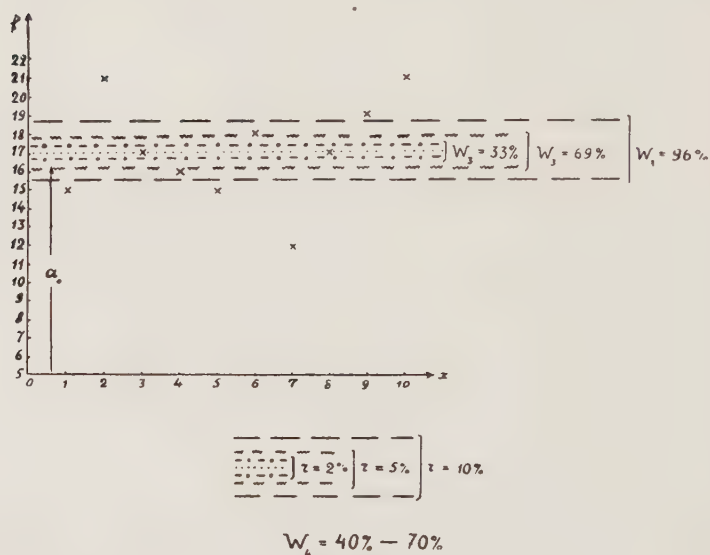


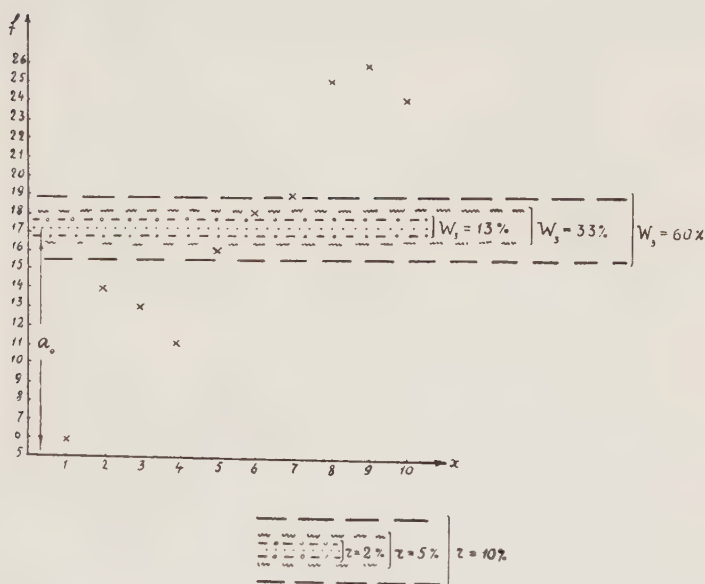
Fig. 7a

Ces résultats sont portés également sur la même figure. La probabilité de l'hypothèse elle-même (que la couche est vraiment horizontale) est déterminée par les chiffres:

40 %	si l'on néglige les écarts de	10 %
55 %	" " " " " "	15 %
70 %	" " " " " "	20 %

Pour rendre des résultats plus clairs, imaginons un deuxième cas: les observations nous ont fourni les données de la fig. 7b. La simple évidence est que la couche n'est pas plane. Cependant, pour éprouver la théorie, appliquons l'hypothèse de la couche plane. On a les probabilités suivantes pour la valeur de la profondeur a_0 (fig. 7b):

13 %	pour les écarts de	2 %
33 %	„ „ „ „	5 %
44 %	„ „ „ „	7 %
60 %	„ „ „ „	10 %



$$W_4 = 1\%$$

Fig. 7b

et, ce qui est plus important, les probabilités de l'hypothèse même (que la couche est plane):

est moins de 1 %	pour les écarts de	10 %
„ „ „ 1 %	„ „ „ „	15 %
„ „ „ 1 %	„ „ „ „	20 %

On voit qu'elles sont minimales, en accord complet avec l'évidence. Au contraire, appliquant aux données de cette figure 7b, l'hypothèse d'une couche inclinée (ce qui est représenté sur la fig. 7c) on obtient: les probabilités des constantes géométriques déterminant la couche:

4 %	pour les écarts de	2 %
23 %	„ „ „ „	5 %
36 %	„ „ „ „	7 %
55 %	„ „ „ „	10 %

et les probabilités correspondant à l'hypothèse de la couche inclinée:

20 %	pour les écarts de	10 %
20 %	„ „ „ „	10 %
30 %	„ „ „ „	15 %
40 %	„ „ „ „	20 %.

Comme on pourrait s'y attendre, même sans calcul, elles sont beaucoup plus élevées que dans le cas où nous avons appliqué à ces données l'hypothèse de

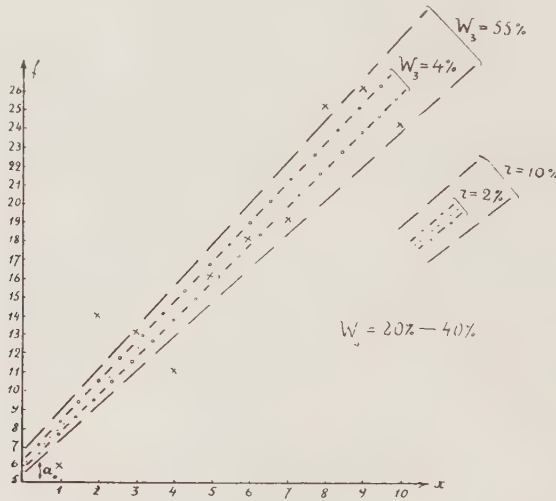


Fig. 7c

la couche plane. Alors, et ceci est le point capital, nous sommes donc capable non seulement de dire vaguement que les probabilités des unes sont plus grandes que celles des autres, mais de les estimer exactement.

On peut imaginer encore un exemple, fourni par la fig. 7d, pour donner une idée claire de l'influence de la disposition plus ou moins serrée des points autour d'une ligne hypothétique. Ici les résultats sont: les probabilités des constantes:

9 %	pour les écarts de	2 %
40 %	„ „ „ „	5 %
57 %	„ „ „ „	7 %
75 %	„ „ „ „	10 %

et les probabilités de l'hypothèse elle-même (que la couche est inclinée):

30 %	pour les écarts de	10 %
45 %	„ „ „ „	15 %
55 %	„ „ „ „	20 %

Mais ce n'est que rarement que l'on rencontre dans la pratique des cas aussi

simplifiés. Le cas typique est donné par la fig. 8, il correspond à une structure géologique réelle, toujours plus ou moins compliquée. Ici nous voyons plusieurs traces de couches horizontales ou inclinées. Presque en règle générale ces traces sont interrompues, soit parce qu'elles ne sont pas continues en réalité, soit parce que la réfraction et la réflexion des ondes sismiques, ondes indicatrices, sont gênées à cause des couches mal délimitées et d'autres irrégularités

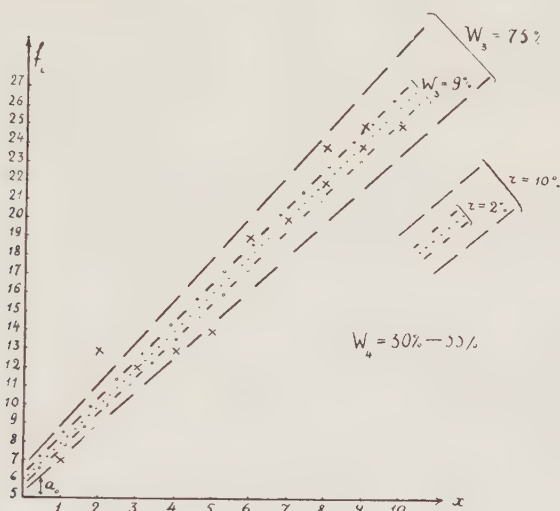


Fig. 7d

de structure. Le prospecteur doit, se basant sur des coupes semblables à celle de la fig. 8, tracer des lignes moins indéterminées que celles qu'on voit dans cette figure et décider où les traces interrompues doivent être liées par des lignes hypothétiques, et où, au contraire, on doit indiquer les lignes de discordance géologique (failles, etc.). Evidemment, la connaissance préalable de terrain peut rendre cette opération suffisamment sûre en ses résultats, mais ces résultats probables (structures des terrains voisins, données d'autres méthodes de prospection, etc.) sont loin d'être toujours à notre disposition.

Il est clair, sans explication, que, sans ces données supplémentaires et ces observations préalables, les résultats tirés des coupes du type de la fig. 8, ne sont pas très fondés. Et il est également clair que ces résultats seront beaucoup plus sûrs si, au lieu de la fig. 8, on part de la fig. 9. Cette figure représente la même structure, étudiée à l'aide des mêmes observations avec des ondes sismiques. Mais sur cette figure ce ne sont pas les seuls résultats moyens qui sont représentés; les résultats du calcul de l'estimation (dans le sens développé ci-dessus) y sont aussi tracés. Chaque petit groupe des points expérimentaux de la fig. 9 correspond à un cas traité de la même manière que sur les figures 7a, 7b et 7c.

Les conclusions qu'on tirera de la fig. 9 seront, sans doute possible, beaucoup plus fondées que celles basées sur la fig. 8. Il est indiscutable que la connais-



Fig. 8

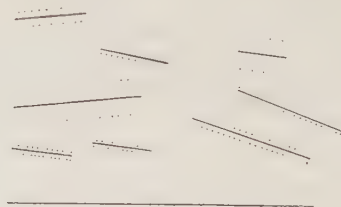


Fig. 9

sance d'autres faits (voir plus haut) p.e. des données géologiques nous amenera à des conclusions encore plus sûres. Cependant, déjà sans de telles connaissances, nos résultats seront plus proches de la réalité. Et encore, la probabilité de ces résultats sera estimée numériquement.

SUPPLÉMENT

Les idées exposées dans la partie principale de cet article, peuvent être résumées en langage mathématique comme suit:

§ 1. En partant des données (D_i) ($i = 1, 2, \dots, J$) des observations et des mesures fournies par telle ou telle autre méthode de prospection géophysique ou géologique, on doit s'occuper consécutivement des quatre problèmes suivants:

I. Trouver une hypothèse (H) convenable, mais suffisamment vague; en langage mathématique, — trouver une expression suffisamment étroite pour caractériser les données D_i et, en même temps, suffisamment large pour couvrir une bande contenant les données D_i , mais aussi les voisines de D_i . Autrement dit, l'expression choisie pour exprimer l'hypothèse H , doit contenir des paramètres (p_k) encore indéterminés — $H(i, p_k)$.

II. Déterminer les valeurs numériques (P_k) de ces paramètres, valeurs faisant le mieux coïncider l'expression $H(i, p_k)$ avec les données D_i . Par exemple, on peut exiger, ce qui est raisonnable mais pas obligatoire, que les P_k soient tirées de la condition que

$$\sum_{i=1}^J [H(i, p_k) - D_i]^2 \Big|_{p_k \rightarrow P_k} \longrightarrow \min. \quad (1)$$

prenne la valeur minimum pour $p_k = P_k$. On peut proposer d'autres conditions pour déterminer les P_k ; mais cependant, pour simplifier les choses, on se limite ici au cas où on obtient les P_k à l'aide de la condition (1).

III. Estimer la certitude des valeurs calculées P_k ou, pour mieux dire, la certitude de la bande admise autour des valeurs P_k exactes:

$$P_k - \Delta P_k < p_k < P_k + \Delta P_k \dots \dots \dots (2)$$

Les explications sont déjà données dans la partie principale (voir les figures

6, 7a, 7b, 7c, 7d et la description de ces figures). On trouvera quelques remarques supplémentaires au § 3 ci-dessus. Enfin:

IV. Estimer la certitude de l'hypothèse H elle-même.

§ 2. En pratique on se borne habituellement aux problèmes I et II; soit que l'on passe outre aux problèmes III et IV, soit que l'on ne donne que des remarques verbales: „certitude bonne”, „mauvaise”, etc., remarques souvent arbitraires. *Le but principal que nous nous posons ici est d'indiquer la nécessité de calculer les certitudes correspondantes à III et IV.*

Le problème IV — estimation de l'hypothèse H elle-même — ne diffère pas sensiblement du point de vue mathématique de III. De fait, on peut toujours introduire une hypothèse plus générale que H(i) par:

$$H_{\text{gén.}}(i) = H(i) + \varepsilon f(i), \quad (3)$$

où ε — est un nouveau paramètre. Si l'hypothèse n'est pas absurde — et c'est le seul cas qui mérite d'être étudié — en déterminant à l'aide de la condition (1) les paramètres, on trouvera que la valeur numérique de ε est petite. On utilise ce fait pour substituer logiquement la certitude de telle ou telle autre valeur ε (ou de telles ou telles autres bandes de valeurs ε) à la certitude de l'hypothèse H. Ainsi on estime dans le problème III la certitude de p_k [partant de l'expression $H(i, p_k)$], tandis que dans le problème IV on estime la certitude de p_k et ε [partant de l'expression (3)]. Numériquement les résultats sont différents, mais théoriquement c'est la même question et nous ne considérons, dans ce qui suit, que le problème III.

Enfin, pour résoudre le problème ainsi posé, on peut envisager trois méthodes: la première est basée sur le test Ψ de *Pearson* et les idées de *Fisher*, qui sont universellement connus. Nous n'en parlerons pas. Mais on peut indiquer encore deux méthodes: une méthode de simple énumération (voir la figure 6 plus haut) et une autre basée sur les considérations de l'uniformité (données dans les notes citées *).

§ 3. La méthode énumérative consiste en deux opérations. On commence par départager l'espace (D_i, i) ou (D_i, x_i) (l'indice énumératif i peut représenter une série à plusieurs „dimensions”, aussi bien qu'à une seule) en N domaines Δ_n dont les limites coïncident avec les fonctions $H(i, p_{k,n})$. Les valeurs numériques $p_{k,n}$ correspondent à la limite entre le domaine (n) et le domaine $(n+1)$. La grandeur n prend les valeurs $1, 2, 3 \dots N$. Après cette opération on compte les points D_i se trouvant dans les domaines. Soient $U_1, U_2 \dots U_n$ — les nombres respectifs des point dans les domaines $\Delta_1, \Delta_2 \dots \Delta_n$. Soit:

$$U = \frac{1}{N} \sum_{n=1}^N U_n \quad (4)$$

Ainsi on peut accepter que les grandeurs

* Loc. cit. C. R. Acad. Sci., t. 231, p. 1282 (1950) et loc. cit. t. 236, p. 1849 (1953).

[illegible]

expriment avec une exactitude suffisante les probabilités des domaines Δ_n et par conséquent les probabilités des bandes

$$P_{k, n} < p_k < P_{k, n+1} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

s'il n'existe aucune préférence théorique pour certaines des valeurs D_1 et si I (— le nombre des données D_1) est grand par rapport au nombre N .

Indiquons maintenant par $n = 1$ le domaine où se trouvent les P_k , valeurs les plus probables des paramètres p_k . Appliquant cette notation on a :

$$P_{k, 1} < P_k < P_{k, 1 + 1} \dots \dots \dots (7)$$

D'après la méthode énumérative, la certitude de ces valeurs les plus probables [proprement dit de toute la bande (7)] sera estimée par la probabilité $W_1 = \frac{1}{2^{10}}$.

Un simple exemple de cette méthode est présenté dans la figure 6, cas où D_i est une série à une seule „dimension”. Nous avons déjà considéré cet exemple plus haut ; considérons le brièvement encore une fois dans les notations que nous venons d'introduire. Imaginons que D_i , les données des observations et des mesures, doivent représenter géométriquement une couche inclinée. Cette couche est, à son tour, exprimée mathématiquement par la fonction $H = p_i x_i$ ayant un seul paramètre à déterminer. Les limites entre les domaines sont déterminées par P_{ik} . Ces valeurs sont (voir la figure) :

$$P_{11} = 0; P_{12} = \text{tg } 30^\circ; P_{13} = \text{tg } 42^\circ; P_{14} = \text{tg } 48^\circ; P_{15} = \text{tg } 60^\circ; P_{16} = \infty. \quad (8)$$

Les signes : $v, x, \odot, \sqcap, \square$ indiquent les points D_i appartenant respectivement aux domaines premier, second, etc. (voir la partie principale, p. 5). Si nous estimons que les conditions sus-mentionnées s'appliquent, on trouve les probabilités :

pour: $0 < p_1 < \operatorname{tg} 30^\circ$; $W_1 = 1/15$; pour: $\operatorname{tg} 30^\circ < p_1 < \operatorname{tg} 42^\circ$; $W_2 = 4/15$;
pour: $\operatorname{tg} 42^\circ < p_1 < \operatorname{tg} 48^\circ$; $W_3 = 6/15$; pour: $\operatorname{tg} 48^\circ < p_1 < \operatorname{tg} 60^\circ$; $W_4 = 3/15$;
pour: $\operatorname{tg} 60^\circ < p_1 < \infty$; $W_5 = 1/15$. [$\sum W_i = 1$, comme il doit être].

Les valeurs les plus probables sont : $\text{tg } 42^\circ < p_1 < \text{tg } 48^\circ$; l'inclinaison la plus probable correspond au domaine Δ_3 , la certitude de ce résultat est $6/15 = 40\%$.

§ 4. Si les conditions du paragraphe précédent ne sont pas réalisées (c'est-à-dire que J n'est pas grand par rapport à N , etc.), il est inévitable de revenir aux méthodes plus exactes. Pour cela on prend en considération les écarts entre les valeurs théoriques données par H et les données existant de fait. Si l'on peut fixer la valeur théorique et observer (ou mesurer) plusieurs écarts entre cette valeur pour un seul indice i (par exemple pour $i = 1$), on obtient une distribution des probabilités pour cet indice. Nommons cette probabilité (G_1). On répète cette opération pour les $i = 2, i = 3$, etc. Si toutes les distributions

sont gaussiennes, on arrive au test Ψ de Pearson et la méthode de Fischer est applicable.

Mais la difficulté principale réside souvent dans le fait qu'on ne connaît qu'une seule valeur pour chaque i ; par exemple la valeur numérique correspondant à i dans la série :

$$D_i - H(i, P_k) \dots \dots \dots (G_2)$$

(voir § 1). Dans ce cas il est très dangereux de faire quelque supposition sur les distributions nécessaires pour la méthode de Pearson-Fisher; la seule distribution, qui nous est connue, est la série (G_2) . Elle ne coïncide pas (loc. cit. C. R. Acad. Sci., t. 236, p. 1849, 1953) avec (G_1) . Si les distributions (G_1) sont gaussiennes, les probabilités des éléments de la série :

$$\sum_i [D_i - H(i, p_k)]^2, \dots \dots \dots (G_3)$$

comme on le sait, ne le sont pas. Plusieurs malentendus ont surgis, parce que l'on oublie souvent que les p_k ne sont pas toujours les P_k , et que l'on ne connaît en géophysique que (G_2) .

Au contraire, si on ne connaît rien sur (G_1) et si la distribution de la série (G_2) est gaussienne, il est possible [voir loc. cit. C. R. Acad. Sci., t. 231, p. 1282 (1950) et t. 236, p. 1849 (1953)] en appliquant le principe de l'uniformité d'admettre que la distribution de (G_3) est aussi gaussienne. Cela simplifie profondément tous les calculs et nous donne les formules très maniables. On peut citer, par exemple, les formules correspondant aux cas où la fonction $H(i, p_k)$ qui exprime l'hypothèse admise, ne dépend des paramètres p_k que linéairement. L'hypothèse d'une couche plane (horizontale ou inclinée) se trouve justement parmi ces cas : $H = p_1 + i p_2$. Pour arriver aux formules immédiatement applicables nous nous bornons aux cas de dix données expérimentales; φ sera la fonction de Gauss dont les tableaux numériques se trouvent dans tout manuel de mathématiques. La probabilité que les valeurs des paramètres se trouvent entre $P_1 - \Delta p_1$ et $P_1 + \Delta p_1$ d'une part et entre $P_2 - \Delta p_2$ et $P_2 + \Delta p_2$ de l'autre (voir les fig. 7c et 7d — le cas d'une couche inclinée) sera exprimée :

$$W_{\Delta P_1, \Delta P_2} = \varphi \left(\frac{6,71 \Delta p_1 + 36,9 \Delta p_2}{\sqrt{\Sigma D_i^2 - 10 P_1^2 - 110 P_1 P_2 - 385 P_2^2}} \right) \cdot \varphi \left(\frac{19,3 \Delta p_2}{\sqrt{\text{simile}}} \right) \quad (9)$$

Pour la couche horizontale ($P_2 = 0$, $\Delta p_2 = 0$) la formule sera encore plus simple (voir aussi les fig. 7a et 7b) :

$$W_{\Delta P_1} = \varphi \left(\frac{6,71 \Delta p_1}{\sqrt{\Sigma D_i^2 - 10 P_1^2}} \right) \dots \dots \dots (10)$$

On trouvera quelques exemples numériques dans loc. cit. C. R. Acad. Sci., t. 234, p. 1428 (1952); ils sont en partie représentés ici par les figures 7a, 7b, 7c et 7d. Pour l'application voir le détail dans la partie principale de cet article, dans les notes citées et spécialement dans notre mémoire cité dans page 39. Il nous semble que cette dernière méthode doit prendre la place prépondérante dans la pratique de la prospection.

A PRACTICAL EXAMPLE OF AN ANISOTROPIC VELOCITY-LAYER *

BY

J. G. HAGEDOORN **

ABSTRACT

The results obtained from a number of seismic velocity well-logging surveys and adjacent refraction sections are compared. The velocities derived by these two methods for a certain layer are found to differ appreciably. This is shown by presenting the time-depth relations of the well-surveys and the time-distance relations of the refraction sections at three locations, plotted on graphs with sloping depth- and distance axes.

I. GENERAL

The results presented were obtained at three locations about ten kilometers apart. At the first location velocity determinations were made in two wells, only twelve hundred meters apart, one of which was situated at the intersection of two refraction lines. At the second location only one well, situated at the intersection of two refraction lines, was shot. The third case concerns a well situated at a distance of 1250 meters from a single refraction line and this case is included because a very clear velocity survey in the well was obtained.

The three well-locations with adjacent refraction sections are treated as three separate examples on figures 1, 2 and 3. The locations of wells and shotpoints are shown in the lower left-hand corner of each figure. The location of a well is marked by the same cross that is used to mark the travel-times in the well-survey graph for that well. The locations of the seismographs are marked by dots and the locations of the shotpoints are marked by different circles and squares corresponding to the time-values in the refraction graph from the same shotpoints.

The shotpoints form fairly symmetrical patterns in regard to the wells and the distances to the wells are such that the time-values recorded correspond to parts of the underlying layers approximately at the wells.

2. COMPARISON OF VELOCITIES OBTAINED FROM WELL-SHOOTING AND FROM REFRACTION

By plotting the time-values of the wells against the depths it is found that the observed graphs can be approximated by a number of straight line segments,

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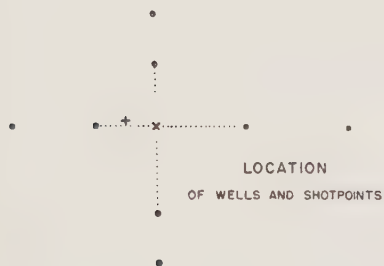
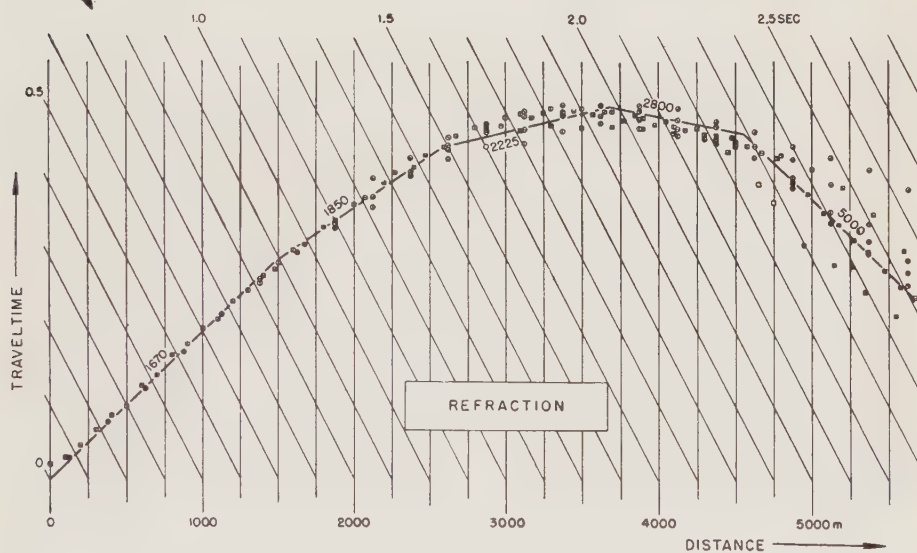
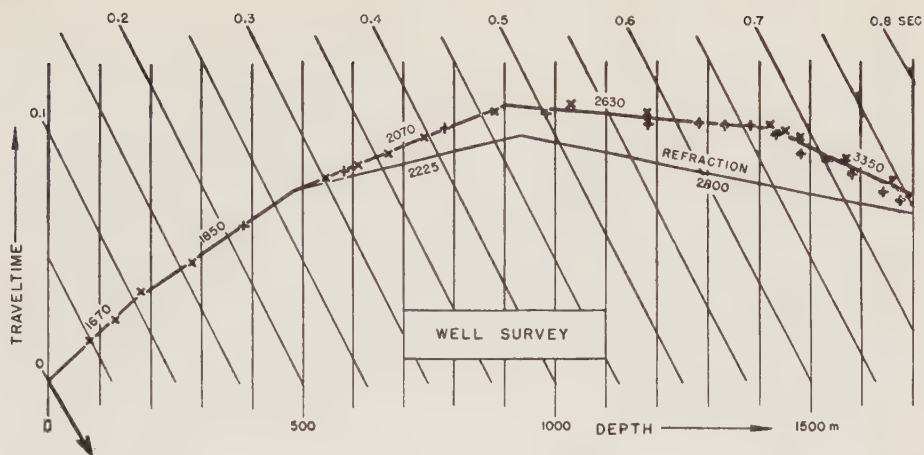


Fig. 1

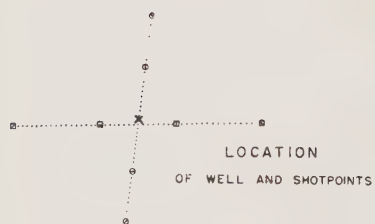
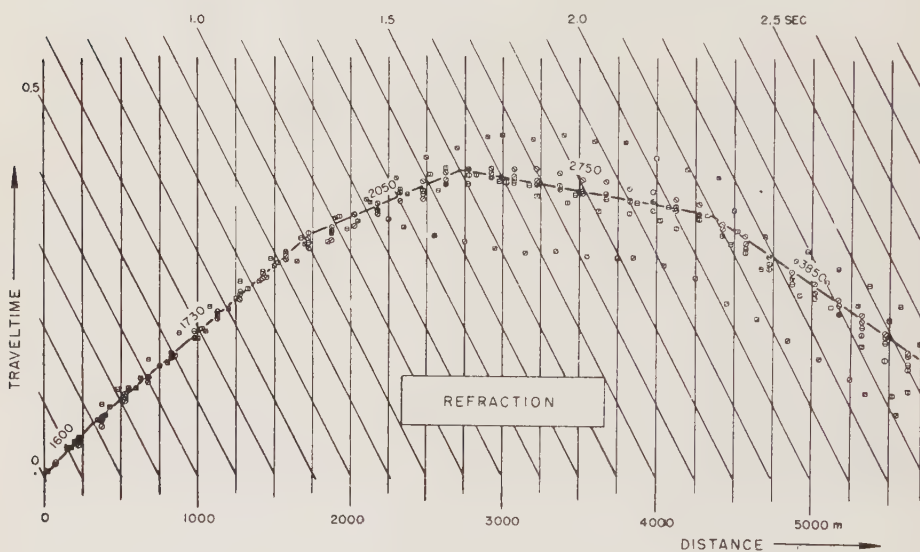
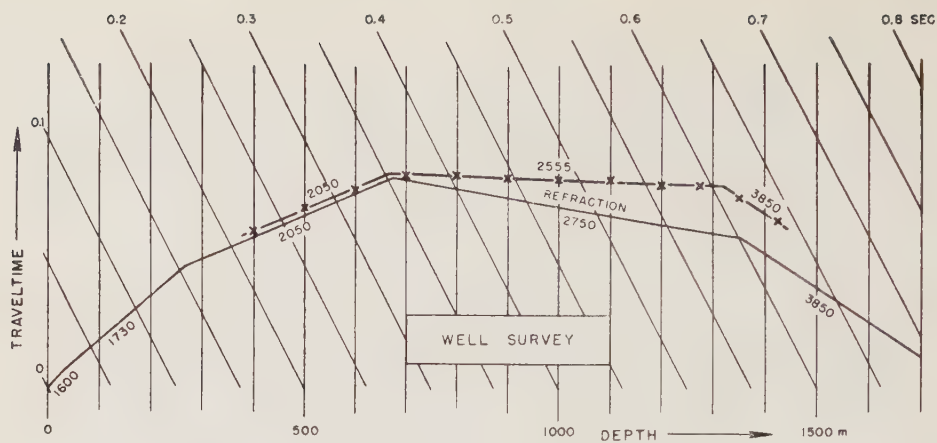


Fig. 2

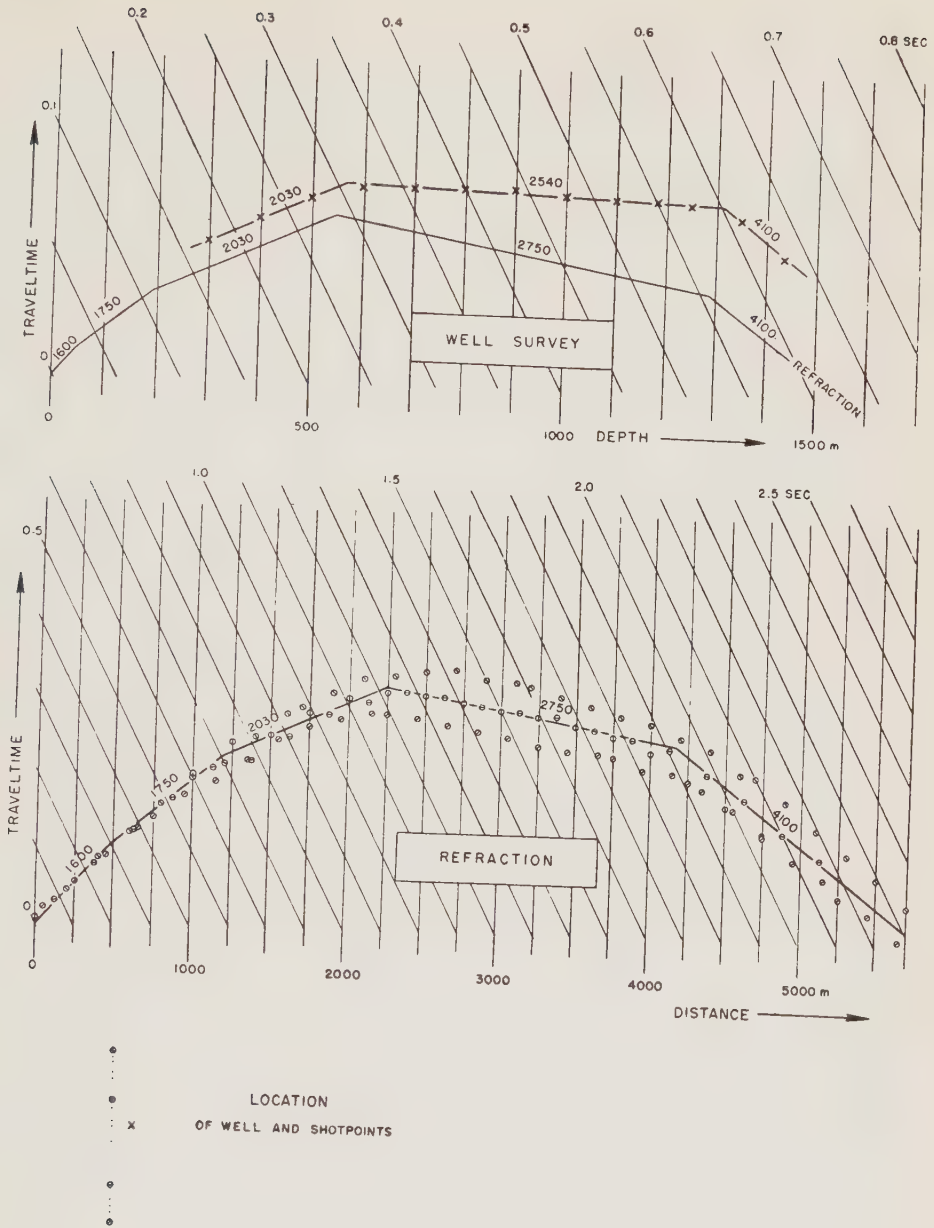


Fig. 3

each representing a layer with constant velocity. Velocity distributions determined by this method from well-surveys refer, of course, to velocities in a nearly vertical direction and can therefore be directly applied to depth calculations in normal reflection work.

Refraction shooting and interpretation, however, involve in addition trajectories and their velocities in less steeply sloping and in horizontal directions. By approximating refraction time-distance graphs by a number of straight line segments it is also possible to determine a number of layers with constant velocities. The velocities found, however, are fundamentally horizontal velocities.

By comparing the velocities obtained from well-surveys and corresponding refraction sections it is possible to ascertain whether or not the horizontal and vertical velocities in a certain layer are different. It is not, however, possible to evaluate any intermediate velocities of sloping paths without assuming certain physical properties to explain the anisotropy of the layer. It could, for example, be assumed that the layer consists of alternating thin bands of two different velocities. A refraction graph would indicate the higher velocity and the well survey a lower vertical velocity of intermediate value. Thus the actual velocity of the low speed bands would not be determined by any of the measurements.

3. GRAPHS WITH SLOPING DISTANCE AXIS

The velocity of the layer showing the discrepancy between the well-surveys and refraction shooting is in the neighbourhood of 2500 m/s. In order to present a clear picture of the velocity observed with the aid of the time-depth and time-distance graphs, these are plotted in such a way that the slope of the curve is horizontal for a velocity of 2500 m/s. This is achieved by plotting on a co-ordinate system where the axes are not mutually perpendicular, but where the time-axis is vertical and the depth- or distance axis is sloping one second per 2500 m. This system has certain advantages. The distances from the shot-points to the seismographs are known to about 0.1 meter. The observed time values, however, are accurate to only approximately two to five milliseconds, corresponding to distances of about three to twenty meters. This means that in practice we are concerned with variations and errors in the time values only. The time-scale must be large enough for these variations to be clearly discernable and this leads to graphs that are not only cumbersome but in which the variations of the time-values from a mean curve are not in a direction vertical to this curve. This is confusing because the variations apparently become less for steeper curves. Furthermore the eye is particularly sensitive to differences of slope near the horizontal (and the vertical).

The time- and distance-scales of the refraction graphs have both been chosen smaller than the corresponding scales of the well-survey graphs, in the same proportion of 10 to 3. This means that a certain slope corresponds to the same velocity in all graphs.

4. FIRST EXAMPLE

Figure 1 shows the time-depth graph for the two wells and the time-distance graph of the time-values registered from eight shotpoints on two refraction lines intersecting orthogonally at one well.

The plotted points of the two well-surveys define the five straight line segments fairly well, corresponding to five layers with constant vertical velocities. The depths of the interfaces seem to be the same in both wells, with the exception of the deepest, which clearly shows a difference of about 50 m. There is naturally some latitude in choosing the straight line segments because the mean error in the time-values is around one to two milliseconds. It is, however surprising how small this latitude is found to be when actually trying to fit in the straight line segments. It is in fact not possible to use slopes corresponding to velocities of multiples of a hundred meters, but multiples of ten meters must be used to obtain a reasonable fit.

By carefully scrutinising the trend of the values from each individual shotpoint in the refraction graph it is seen that the slopes of the different straight line segments are also fairly well defined. A difference in slope observed for points from different shotpoints can be explained by the sloping of the layers, but this, however, appears to be small in this case. Differences in depths account for the fact that the changes from one slope to another occur at different distances. Despite the variations and irregularities of the different series of points, it is possible to draw a number of straight line segments resulting in a mean curve. The slopes of these segments are rather well defined and because of the symmetrical location of the shotpoints, these slopes will correspond closely to the actual horizontal velocities of the different layers.

The first two straight line segments in the refraction graph can be drawn to correspond with the velocities and depths of the first two layers in the well-survey graph. The following segments in the refraction graph can, however, not be drawn to correspond to the well survey. A fairly good fit is obtained by straight line segments with slopes corresponding to 2225, 2800 and 5000 meters per second. The well survey curve that would be found for a velocity distribution corresponding to the mean refraction curve has been drawn as a thin line in the well-survey graph. From this it can be seen that the layers with vertical velocities of 2070 and 2630 m/s actually correspond to the layers derived from the refraction graph, with horizontal velocities of 2225 and 2800 m/s.

The depth of the layer with a velocity of 5000 m derived from the refraction graph would be about 1800 m. Apparently the layer with a velocity of 3350 m/s observed in the well-survey does not register as first arrivals before the 5000 m/s layer. This can be seen by plotting the first arrivals of this 3350 m/s layer, observed in the well-survey, in the refraction graph as the interrupted straight line.

The depth of the interface between the 2225 and the 2800 m/s layers, determined from the refraction results, is found 30 m deeper than the depth of the

interface between the 2070 and the 2630 m/s layers found in the well-survey. This can be accounted for by the fact that in calculating the depth from the refraction graph, the velocity of 2225 m/s has also been used for the sloping paths down and up through this third layer. By assuming this velocity to be 2070 m/s, the interface is found to be 70 m shallower, so that it is clear that the depths found in the well-survey and those from the refraction results can be made to check by assuming an intermediate velocity for the sloping paths.

5. SECOND EXAMPLE

In this case the well-survey does not show measurements at sufficiently shallow depths to ascertain the velocities of the first layers. The records obtained were, however, of very good quality and each value in the well-survey graph is the mean of four values obtained from shots from four directions. The values can therefore be considered accurate to within one millisecond.

The refraction results were obtained on two refraction sections crossing each other orthogonally at the location of the well. The time-values from the shot-points marked as circles show very little variation, the layers being nearly horizontal in this direction. In the direction at right angles to this, the layers are fairly steep, resulting in more confusing time-distance curves from the shot-points marked as squares.

The first part of the refraction graph, corresponding to the region not registered in the well-survey, can be approximated by two straight line segments corresponding to layers of 1600 and 1730 m/s.

The next part of the time-distance curve can be approximated by a straight-line segment with the same slope as the first segment in the well-survey graph. The next part, however, shows a definitely steeper slope than the corresponding part in the well-survey. The deepest part in both the well-survey and the refraction graph can be approximated by a straight line with the same slope, corresponding to 3850 m/s.

By assuming the interface between the 2050 m/s and the 2750 m/s layer to be at a depth of 670 m, the straight line with a slope corresponding to 2750 m/s in the refraction graph was constructed and it is seen to be a fair mean through the points.

The straight line segment in the refraction graph with a slope corresponding to 3850 m/s fixed the interface between the 2750 m/s and the 3850 m/s layer 35 m deeper than that found in the well-survey for the interface between the 2555 m/s and the 3850 m/s layer. If, however, we assume the velocity of the sloping paths through the 2555 to 2750 m/s layer to be 2555 m/s instead of 2750 m/s, the interface is found 55 m shallower than in the well-survey. This means, exactly as in the first example, that the sloping paths have an intermediate velocity.

6. THIRD EXAMPLE

In this case it is not possible to compare the depths found from the well-

survey and the refraction results because nothing is known of the slopes of the layers between the well and the refraction section. A comparison of the velocities is however possible.

The first layer of 2030 m/s recorded in the well-survey corresponds to the same velocity in the refraction graph for the third straight line segment.

The slope of the straight line segment corresponding to a layer of 2540 m/s in the well-survey is particularly well defined and by roughly comparing its depth with the depth of the 2750 m/s layer found from the refraction results, in which it is also very well defined, it is quite clear that in both cases the same layer is involved.

7. CONCLUSION

The evidence from the three examples seems to show conclusively that at all three locations a layer is observed with a vertical velocity of 2550 m/s and a horizontal velocity of 2750 m/s. In the first example a similar discrepancy was found for a shallower layer, but this was not found in the other examples. The quality of the results obtained from this shallower layer are, however, not at all as good as those found for the next layer.

It is quite well possible that some amount of anisotropy is more a rule than an exception because most layers are more or less stratified horizontally so that the vertical velocities are mean values and horizontal velocities are maximum values. This seems quite feasible for the layers involved in these examples which consist mostly of shaly clays. However even bands of as much as 50 m thick could easily escape notice in well-surveys because in current practice the measured depths are 50 m or more apart.

The explanation for anisotropy can also be sought for in another direction. The distance travelled by an impulse in refraction work is roughly four times the distance travelled in well-surveys. Low frequency waves suffer less absorption than high frequency waves, so that with larger distances the frequency content of an impulse is shifted towards lower frequencies. If, corresponding to chromatism of optical rays, the velocity increases with lower frequency we could expect to find as a rule higher velocities from refraction results than from well-surveys.

In the second and third case, however, the velocity found for the deepest layer is apparently the same when derived from either well-survey or refraction results, so that it would have to be assumed that only the 2500-2750 m/s layer shows "chromatism". The accuracy of the velocities found in the well-surveys for the deep layer is, however, not very great and this layer is much more inhomogeneous than the preceding layer, so that the existence of a general "chromatism" cannot be excluded.

DISCUSSION

MR. GASKELL: Have you used the method of least squares to determine the velocities and to what accuracy are the velocities known?

Mr. HAGEDOORN: The method of presenting the actually measured values on a graph with sloping distance axis provides a directly visual evaluation of the velocities and their accuracy, while a method of least squares, though just as good, is less demonstrative. The velocities of the layer involved are determined to an accuracy that certainly lies within 50 m per sec.

Mr. GASKELL: I still think the method of least squares is to be preferred as it gives, to my mind, a more certain value of the velocity and its accuracy.

Mr. VAN DER SLEEN: I have worked in the same territory as Mr. Hagedoorn and have been working on the same subject along similar lines. The results of my investigations conform closely to those presented here.

I wish to add one point to the argument about the use of the method of least squares. That is, that a preliminary clear graphical picture can never be dispensed with, in order to be able to determine which particular points refer to the layer in question. Only after this question has been cleared up can the method of least squares be applied.

Mr. VON HELMS: (abridged) In order to be certain that an anisotropy actually does exist it is necessary to have very thick uniform layers without too much dip. Velocities from refraction measurements tend to show the highest velocities so that very thin bands are very important.

Mr. HAGEDOORN: The results presented refer to a layer of some 700 m. thick with a very small variation in vertical velocity. Some increase with depth can be observed but it is much smaller than the difference in horizontal and vertical velocity. Because of these exceptionally favourable circumstances the interpretation that anisotropy most probably occurs seems to be well warranted in this case.

As to the influence of narrow bands it must be borne in mind that the wavelengths of the seismic waves are in the order of a few hundred meters. This means that narrow bands with extreme velocities can have hardly any influence over the distance involved in refraction work, because they can not transport energy.

Mr. ROSENBACH: Sie zeigten ein Beispiel wobei die Abstand zwischen zwei Bohrungen nur 1200 m. war. Wäre es nicht möglich gewesen von das eine Loch direkt zum anderen zu messen in der Schicht wo es sich um handelte?

Mr. HAGEDOORN: Die eine Bohrung war schon vor dem Krieg gebohrt worden und war nicht mehr zugänglich. Ihre Methode wäre sehr schön und elegant, aber man hat nur an einem einzeln Augenblick die Verfügung über eine Bohrung um Messungen aus zu führen.

EXTENSION TO THREEDIMENSIONAL PROBLEMS CONCERNING AN APPROXIMATE CORRECTION METHOD FOR REFRACTION IN REFLECTION SEISMIC PROSPECTING *

BY

TH. KREY **

ABSTRACT

The formulas derived by the author in a preliminary paper for taking into consideration refraction when dealing with the problem of a vertical plane are extended to the three-dimensional case. Vector analysis is extensively applied. Among others it is shown that in the general case the 3 horizontal twodimensional vectors, i.e.

- 1) the gradient of the time of reflection,
 - 2) the direction of true dip,
 - 3) the vector from the shot point to the projection of the reflecting point,
- point into 3 different directions.

INTRODUCTION

In a preliminary paper (Krey 1951) the author has derived formulas which make possible an approximative consideration of refraction in reflection seismics. These formulas held, however, only for the case of problems dealing with plane vertical sections, i.e. they were valid only for the case of observations being made at a right angle to the strike and moreover it was assumed that the strike of all boundary planes between different velocity-layers above the reflecting horizon concerned was conform to the latter.

It is the purpose of this paper to extend the results obtained formerly to the three dimensional case. It will be shown that the character of the formulas thus derived is maintained and that only some plausible additional terms do appear. Besides, the degree of approximation which can be obtained by the derived formulas, will be shown by two examples.

If in the following attention is directed to passages and formulas in the paper (Krey 1951) the appended note (Kr. 51) is used for simplicity.

ASSUMPTIONS AND NOTATIONS

The assumptions and notations chosen in this paper are similar to those used in (Kr. 51). The letter y , formerly denoting the vertical coordinate, is, however,

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** Seismos G.m.b.H., Hanover.

replaced by the letter z . Instead of this, the letter y is used to denote the second horizontal coordinate. The velocity of propagation $v(x, y, z)$ must be considered as a function of three variables as has been indicated by the manner of writing. The quantities, j , l and i are now replaced by the couples of quantities (j_x, j_y) , (l_x, l_y) and (i_x, i_y) . In doing so $(90^\circ - j_x)$ means the angle

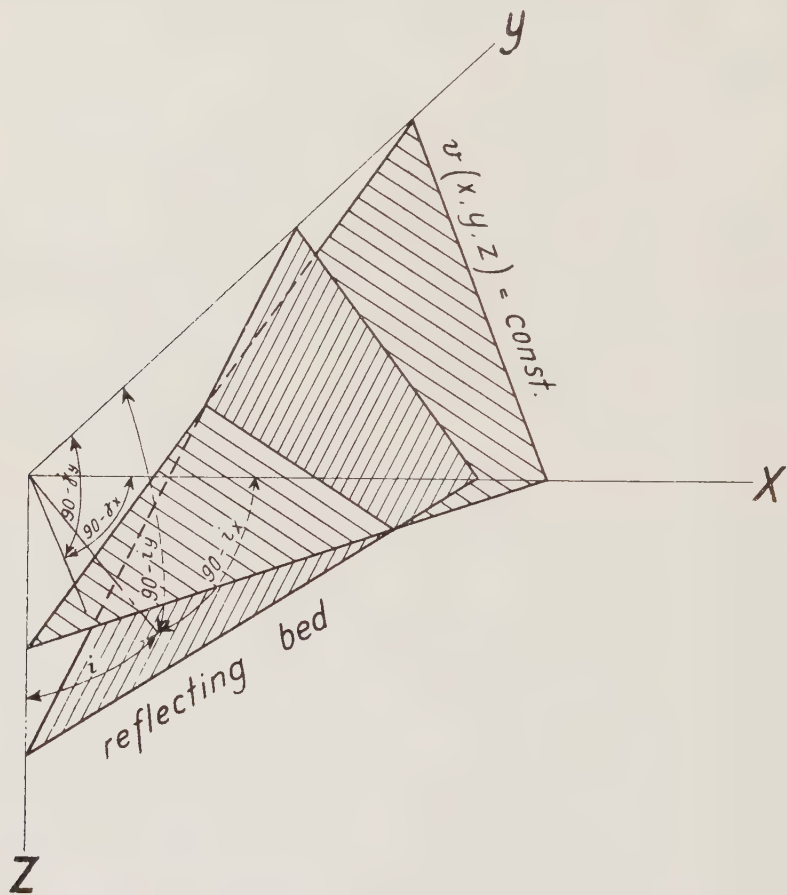


Fig. 1

formed by the normal to the plane $v(x, y, z) = \text{const.}$ with the x -axis, $(90^\circ - l_x)$ the angle formed by the ray, starting from the point $(x_m, y_m, 0)$, with the x -axis, and finally $(90^\circ - i_x)$ the angle formed by the normal to the reflecting plane with the x -axis. The corresponding applies to j_y , l_y and i_y . Besides i_x and i_y will be briefly called the dip components of the reflecting plane. (Figure 1).

Corresponding to and in like sense as in (Kr. 51) the same admissible

neglects are to be valid. See at the top of the pages 469 and 470 (Kr. 51). Thus, it is possible to cancel terms as l_x^4 , $l_x^3 l_y$ or $l_x l_y^3$. But the same holds also for terms containing $l_x j_x^2$, $l_x^2 j_x$, $l_y^2 j_x$, $j_x j_y^2$ or j_x^3 etc.

The Equ. (1) (Kr. 51) is now replaced by

$$j_x = \left(\frac{\partial v}{\partial x} \right) / \left(\frac{\partial v}{\partial z} \right) \quad \text{and} \quad j_y = \left(\frac{\partial v}{\partial y} \right) / \left(\frac{\partial v}{\partial z} \right), \quad \dots \quad (1)$$

and Equ. (2) (Kr. 51) by

$$\frac{t}{2} = \int_0^s \frac{dz}{v(x, y, z)} \quad \dots \quad (2)$$

Thus s is given as a function of t , x and y . (In Carrying out the integration x and y are kept constant). Equ. (3) (Kr. 51) is replaced by

$$\bar{v}(t, x, y) = \frac{s(t, x, y)}{\frac{t}{2}} \quad \dots \quad (3)$$

PATH OF A RAY DEVIATING SLIGHTLY FROM THE VERTICAL DIRECTION

To derive formulas for the three-dimensional case analogous to (9) (Kr. 51) it will be progressed in a way slightly different from that used in the two-dimensional case. It will be started on the principle of variation of the shortest path of light*.

Let a ray, proceeding from a point $(x_m, y_m, 0)$, be given by $x = x(z)$ and $y = y(z)$ with $x' = dx/dz$ and $y' = dy/dz$. It is then according to computations in the sense of the variation principle

$$\delta \int \frac{\sqrt{1 + x'^2 + y'^2}}{v(x, y, z)} dz = 0.$$

This means

$$-\frac{1}{v^2} \sqrt{1 + x'^2 + y'^2} \frac{\partial v}{\partial x} = \frac{\partial}{\partial z} \left(\frac{1}{v} \sqrt{1 + x'^2 + y'^2} \right).$$

As now $x' = l_x$, $y' = l_y$, $\frac{\partial v}{\partial x} = j_x \frac{\partial v}{\partial z}$ and $\frac{\partial v}{\partial y} = j_y \frac{\partial v}{\partial z}$, hence on applying the admissible neglect we have

$$\frac{1}{v} \frac{x'}{\sqrt{1 + x'^2 + y'^2}} = \text{const} - \int_0^z \frac{1}{v^2} \cdot \frac{\partial v}{\partial x} d\zeta \quad \dots \quad (4)$$

In the integral on the right side of (4) the integration has to be carried out along the curved path. It may easily be seen, similarly to pages 470/471 (Kr. 51), that in the sense of the approximations made in this paper the curved path

* I am indebted to Dr. Menzel for this suggestion.

can be replaced by the vertical path, i.e. that the horizontal coordinates can be left constant, e.g. equal to x_m and y_m or equal to x and y . (The resulting error is of the order $l^2 j^2$). It is, however, to be assumed that, before and after the modification of the path of integration, the same planes of discontinuity of $v(x, y, z)$ are passed.

Now, according to Equ. (2)

$$\frac{1}{2} \delta t = \frac{\delta s}{v} - \int_0^s \frac{1}{v^2} \left\{ \frac{\partial v}{\partial x} \delta x + \frac{\partial v}{\partial y} \delta y \right\} dz.$$

(In carrying out the integration x and y are also kept constant here). In considering s as a function of t , x and y it is therefore

$$\frac{\partial s}{\partial x} = v \int_0^s \frac{1}{v^2} \frac{\partial v}{\partial x} dz \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

(Here, too, x and y are kept constant during the integration). In substituting the letter ζ for the integration variable z and replacing s by z it follows after inserting (5) in (4)

$$\frac{x'}{\sqrt{1 + x'^2 + y'^2}} = v \cdot \text{const} - \frac{\partial s}{\partial x} \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

Now it is

$$\frac{x'}{\sqrt{1 + x'^2 + y'^2}} = \sin l_x \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

Hence it follows — if at the same time the constant is fixed —

$$\sin l_x = \frac{v}{v_0} \sin l_{x0} - \frac{\partial s}{\partial x} \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

and accordingly

$$\sin l_y = \frac{v}{v_0} \sin l_{y0} - \frac{\partial s}{\partial y} \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

On the right side of (6) and (9) the quantities x or x_m , y or y_m or any other intermediate values, and s equal to z are to be taken as arguments, i.e. corresponding to the remark given above on the approximative interchangeability of the integration paths and because of

$$\sin l_{x0} v(x, y, z) - \sin l_{x0} v(x_m, y_m, z)$$

being of the order $l^2 j$. The index o in the formulas (9) points, of course, to the argument $z = 0$. The definition of the constants in formula (9) is not objectionable because in the case of $z = 0$, it is according to (5)

$$\frac{\partial s}{\partial x} = \frac{\partial s}{\partial y} = 0.$$

A RAY REFLECTED IN ITSELF AND CORRECTION FOR REFRACTION IN THE CASE OF CONSTRUCTING THE IMAGE POINT

Now let $x_s, y_s, 0$ be the coordinates of the shotpoint and X, Y, Z those of the point of reflection, $\bar{i}_x$ and $\bar{i}_y$ the dip components as obtained from the construction of the image point. The following equation is then an analogon to (16) (Kr. 51)

$$\sin \bar{i}_x = -\bar{v} \frac{\partial T}{\partial x} \quad \text{and} \quad \sin \bar{i}_y = -\bar{v} \frac{\partial T}{\partial y} \quad . \quad . \quad . \quad (16)$$

Correspondingly, we write as an analogon to (15) (Kr. 51)

$$\sin i_{x0} = -v_0 \frac{\partial T}{\partial x} \quad \text{and} \quad \sin i_{y0} = -v_0 \frac{\partial T}{\partial y} \quad . \quad . \quad . \quad (15)$$

where $T = T(x, y)$ is the time of reflection, dependent on the location of the seismograph, with the derivations to be carried out at the shot point.

From (15), (16) and (9) it follows then

$$\sin i_x = \frac{v}{\bar{v}} \sin \bar{i}_x - \frac{\partial s}{\partial x} \quad \text{and} \quad \sin i_y = \frac{v}{\bar{v}} \sin \bar{i}_y - \frac{\partial s}{\partial y} \quad . \quad (17)$$

On the right side of (17) x_s, y_s and $s = Z$ are to be taken as arguments, but X, Y and $s = Z$ might be chosen as well.

Relative to the quantity i and the azimuth α_x of the true dip (i.e. the angle with the positive x -axis) it follows now (Fig. 1)

$$\begin{aligned} \sin i &= \sqrt{(\sin^2 \bar{i}_x + \sin^2 \bar{i}_y)} = \\ &= \sqrt{\left(\frac{v^2}{\bar{v}^2} (\sin^2 \bar{i}_x + \sin^2 \bar{i}_y) - 2 \frac{v}{\bar{v}} \left(\sin \bar{i}_x \frac{\partial s}{\partial x} + \sin \bar{i}_y \frac{\partial s}{\partial y}\right) + \left(\frac{\partial s}{\partial x}\right)^2 + \left(\frac{\partial s}{\partial y}\right)^2\right)} \end{aligned} \quad . \quad . \quad . \quad (17')$$

$$\operatorname{ctg} \alpha_x = \frac{\sin \bar{i}_x}{\sin \bar{i}_y} \quad . \quad . \quad . \quad . \quad . \quad . \quad (17'')$$

The application of the equations (17') and (17'') requires that (17') is invariable to rotation of the x, y coordinate system and that α changes exactly as the coordinate system is rotating. If $\sin i_x$ and $\sin i_y$ are taken as components of a vector $\sin i$ it will easily be seen that the above mentioned requirements are met. Equations (17) may, namely, then be written as follows

$$\sin i = -v \operatorname{grad} T - \operatorname{grad} s \quad . \quad . \quad . \quad . \quad (17a)$$

If now the vector defined by the components $\sin \bar{i}_x$ and $\sin \bar{i}_y$ is denoted by $\sin \bar{i}$ it follows finally

$$\sin i = \frac{v}{\bar{v}} \sin \bar{i} - \operatorname{grad} s \quad . \quad . \quad . \quad . \quad (17b)$$

The most important result of (17), (17') and (17''), in the author's opinion, appears to be the fact that it is possible to make corrections for refraction

at the individual components and to determine the true dip later on. Relative to this, it is also referred to (17) (Kr. 51).

As to the co-ordinates X , Y and Z of the point of reflection it follows if σ denotes the instantaneous length of the curved path of the ray reflected in itself and S the total length of the curved path

$$X = \int_0^S d\sigma \sin l_x, \quad Y = \int_0^S d\sigma \sin l_y,$$

and

$$Z = \int_0^S \frac{d\sigma}{\frac{\partial z}{\partial \sigma}} = \int_0^S d\sigma \left(1 - \frac{1}{2} \sin^2 l_x - \frac{1}{2} \sin^2 l_y\right).$$

From this it follows quite similarly to (Kr. 51), if

$$\bar{X} = S \sin \bar{l}_x, \quad \bar{Y} = S \sin \bar{l}_y \text{ and } \bar{Z} = S \sqrt{1 - \sin^2 \bar{l}_x - \sin^2 \bar{l}_y} \quad (18)$$

are the co-ordinates obtained by the construction of the image point and if we write

$$\sqrt{\sin^2 \bar{l}_x + \sin^2 \bar{l}_y} = \sin \bar{l},$$

$$Z - \bar{Z} = S \left\{ -\frac{1}{2} \sin^2 \bar{l} \left(\frac{M(v^2)}{\bar{v}^2} - 1 \right) + \sin \bar{l} \frac{M(v \text{ grad } s)}{\bar{v}} - \frac{1}{2} M(\text{grad}^2 s) \right\}. \quad (20)$$

In (20) $x = x_s$, $y = y_s$ and $x = S$ or $z = \bar{Z}$ may be taken as arguments. Further, we have

$$X - \bar{X} = S \left\{ \sin \bar{l}_x \left(\frac{M(v)}{\bar{v}} - 1 \right) + \frac{1}{2} \sin \bar{l}_x \cdot \sin^2 \bar{l} \cdot \frac{M(v^3) - M(v) M(v^2)}{\bar{v}^3} - M \left(\frac{\partial s}{\partial x} \right) \right\} \quad (19)$$

and a corresponding expression for $Y - \bar{Y}$. On the right side of (19) $x = x_s$, $y = y_s$ and $z = Z$ from equation (20) are to be taken as arguments. If we should set $z = S$ in (19) the term of 3rd-power would become erroneous. In accordance with this an adjustment has to be made in Equ. (19) (Kr. 51). The arguments written at the foot of the brackets must be designated there correctly $x = x_s$, $y = Y$, with Y being given by (20) (Kr. 51).

If the vector, having the components X and Y , is denoted by R and the other, having the components $\bar{X}$ and $\bar{Y}$, by $\bar{R}$ the equations for $X - \bar{X}$ and $Y - \bar{Y}$ may be combined in the following simple way

$$R - \bar{R} = S \left\{ \sin \bar{l} \left[\frac{M(v)}{\bar{v}} - 1 + \frac{1}{2} \sin^2 \bar{l} \frac{M(v^3) - M(v) M(v^2)}{\bar{v}^3} \right] - M(\text{grad } s) \right\} \quad (19a)$$

It may be seen from the form of (19a) and (20) that Z and $\bar{Z}$ are invariant to the rotation of the x, y co-ordinate system, just as i does, and that X, Y and

$$R - R^* = \frac{1}{2} T v^* \left\{ \sin i^* \left[\frac{M(v) - v}{v} + \frac{1}{2} \sin^2 i^* \frac{M(v^3) - \bar{v} M^2(v)}{v^3} \right] + \right. \\ \left. + M(\text{grad } s) + \frac{M(v)}{v} \text{grad } s \right\} \dots \dots \dots (31a)$$

The arguments to be applied on the right side of the equations (31) and (32) are again the same, as used in (19) or (20), respectively.

In Figures 2 and 3 two examples are given to show the effect of the approximative equations derived in the foregoing text. It is

$$v(x, y, z) = 2000 \text{ with respect to } z \leq 1000 - x \text{ tg } 20^\circ$$

and

$$v(x, y, z) = 3000 \text{ with respect to } z > 1000 - x \text{ tg } 20^\circ.$$

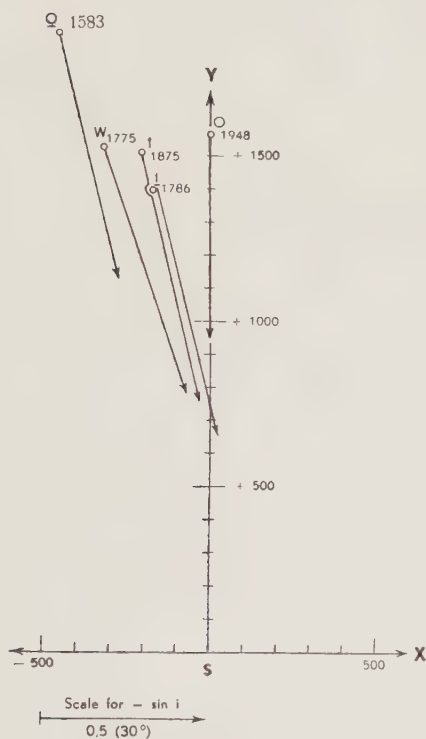


Fig. 2

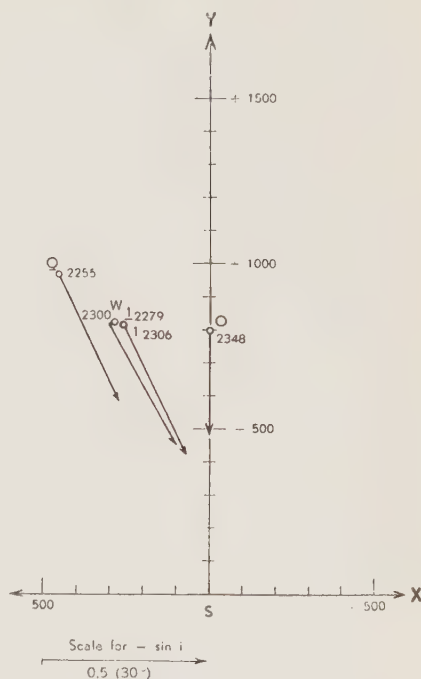


Fig. 3

Thus, only one single refracting plane exists striking parallel to the y-axis and rising in the direction of the positive x-axis. The vector grad s, therefore is lying in the positive direction of the x-axis. Let in both cases be

$$T(0, 0) = 2 \text{ and } \frac{\partial T}{\partial x}(0, 0) = 0.$$

Further it is assumed

$$\text{with regard to the first example } \frac{\partial T}{\partial y}(0,0) = -0,129 \cdot 10^{-3}$$

$$\text{and with regard to the second example } \frac{\partial T}{\partial y}(0,0) = -0,250 \cdot 10^{-3}.$$

The vectors grad T and grad s form a right angle with each other. In Figures 1 and 2 the results of the different methods of approximation which take into consideration refraction are shown in the xy -plane. The shotpoint is denoted by S . As for the rest, the notations are the same as given in (Kr. 51). It denotes: w the true position of the point of reflection—as to the determination of this point see the appendix—, o the position obtained by means of the method of constructing the image point, and i the position resulting from equations (25), (26) after a single application of the iteration process (28). It denotes q the result obtained by the sounding method, and $\bar{i}$ that from Equ. (31) and (32) after a single iteration (28). The amount of Z has been written at each point of reflection. Besides, the vector $(-\sin i)$ representing the direction and in a certain manner the magnitude of the true dip has been drawn at the point of reflection, with the pertinent scale being given in the Figures. It may be seen from the example given in Figure 3 that the approximations obtained by the described methods of correction for refraction are quite good. However, in the example given by Figure 2, where the true dip is close to 60° the discrepancies between i , $\bar{i}$ and w are more considerable. But, it may be noted that the adjustments resulting from the application of the process of correcting for refraction are still quite remarkable.

Besides, from Figures 2 and 3 it is evident that the three vectors R , $\sin i$ and $\sin \bar{i}$ are all pointing in different directions, a fact which in itself arises already directly from the general equations given in this paper. Since $\sin \bar{i}$ and grad T have the same directions it follows that the lines of equal reflection time are not conform with the lines of equal depth. Dürbaum has already pointed to this fact in a paper presented at the meeting of the E.A.E.G. at Hanover, December 1952. But in the author's opinion the other fact must also be emphasized, namely, that R and $\sin i$ have also different directions in the general case.

APPENDIX

The exact computation of rays reflected in themselves in the case of n -dipping and reflecting planes, having constant velocities between the planes, has already been thoroughly treated (Dürbaum 1953). Nevertheless, a new short way of dealing with the problem will be given in the following by extensively applying vector analysis.

Let i_μ^ν be the vector formed in the ν th-layer by the cosines of the direction of the ray reflected in itself at the base of the μ th-layer. Then i_μ^μ is the normal to the base of the μ th-layer. Relative to the ray reflected at the base of the

ν th-layer and to the transition from the ν th to the $(\nu + 1)$ th-layer the following relation consists

$$I - (i_v \cdot i_n + 1)^2 = \left(\frac{v_v + I}{v_v} \right)^2 (I - (i_v \cdot i_n)^2) \quad (\text{Snellius' Law}) \quad . \quad (5I)$$

Besides it is

$$\dot{\mathbf{i}}_n^{\nu+1} = \lambda \dot{\mathbf{i}}_y^\nu + \kappa \dot{\mathbf{i}}_n^\nu \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (52)$$

as the three vectors of Equ. (52) are situated in one plane. Taking into consideration that $(i_n^\nu + 1)^2 = 1$ it follows from (51) and (52)

$$x = + \frac{V_v + I}{V_v} (53)$$

$$\lambda = -\frac{V_y + 1}{V_y} (\dot{i}_y^y \cdot \dot{i}_n^y) + \sqrt{\left\{ I - \left(\frac{V_y + 1}{V_y} \right)^2 [I - (\dot{i}_y^y \cdot \dot{i}_n^y)^2] \right\}} \quad (54)$$

and from this

$$i_n^{y+1} = \frac{V_y + 1}{V_y} \{ i_n^y - i_y^y [(i_y^y \cdot i_n^y) - \sqrt{(\frac{V_y}{V_y + 1})^2 - 1 + (i_y^y \cdot i_n^y)^2}] \} \quad (55)$$

From (55) all i_n^v may be computed successively if i_n^1 is known, and indeed i_n^1 is well defined by v_1 and $\text{grad } T$.

The co-ordinates of the piercing point at the base of the ν th-layer with regard to the ray reflected in itself at the μ th-layer may be combined in the three-dimensional vector R_{μ}^{ν} .

The vector R_μ^μ gives then the co-ordinates of the point of reflection. Besides, let the vector R_μ^0 be defined by the co-ordinates of the shot point $(x_s, y_s, 0)$. Hence it is

[illegible]

and

$$(R_n^{\nu+1} - R_{\nu+1}^{\nu+1}) i_{\nu+1}^{\nu+1} = 0. \quad (57)$$

whence it follows with regard to $(v + 1) < n$

$$R_n^{\nu+1} = R_n^{\nu} + \frac{\{(R_{\nu+1}^{\nu+1} - R_n^{\nu}) \cdot i_{\nu+1}^{\nu+1}\}}{(i_{\nu+1}^{\nu+1} \cdot i_n^{\nu+1})} \cdot i_n^{\nu+1} \quad (58)$$

If T_n is the time of reflection belonging to the point of reflection R_n it is finally

$$T_n = \sum_{\nu=1}^n \frac{|R_n^\nu - R_{n-1}^\nu|}{V_\nu}$$

whence it follows

$$R_n^n = R_n^{n-1} + i_n^n \cdot v_n / T_n - \sum_{v=1}^{n-1} \left\{ \frac{R_n^v - R_n^{v-1}}{v_v} \right\} \cdot \dots \quad (59)$$

From (58) and (59), proceeding from R_n^o , all R_n^v and especially R_n^a , too, may be computed.

ACKNOWLEDGMENT

The author is indebted to Seismos G.m.b.H., Hanover for permitting the publication of this paper and further to Mr. Tüchel for carrying out the translation.

REFERENCES

- TH. KREY, "An Approximate Correction Method for Refraction in Reflection Seismic Prospecting", *Geophysics* XVI, No. 3, 1951, S. 468-485.
H. DÜRBAUM, "Possibilities of Constructing True Ray Paths in Reflection Seismic Interpretation", *Geophysical I*, No. 2, 1953, S. 125-139.

E.A.E.G. ABSTRACT SERVICE

EXPLORATION — GENERAL

1. *Preparing for an Aerial Oil Survey.*

Petroleum Times, Vol. 57, No. 1447, p. 53, Jan. 23, 1953.

The Australian Petroleum Co. Pty. Ltd. and the Island Exploration Co. Pty. Ltd. are to make an airborne magnetometer survey over 35,000 square miles in S. W. Papua between the Gulf of Papua and the Dutch border. It should give a general picture of the attitude of the basement rocks and approximate thickness of the sedimentary deposits in an area where the surface deposits are not exposed.

During the past 16 years, the two companies have spent £ 7, 600,000 in New Guinea and Papua, but so far no oil has been found.

2. *Geophysical Activity in 1951.*

E. A. Eckhardt, Geophysics, Vol. 17, No. 3, pp. 441-451, 1952. — Petroleum Engineer, Vol. 24, No. 5, pp. B74-81, 1952.

Seismic exploration for oil increased by 20.4 % during 1951, mostly in North America. Gravity operations also show an increase. Charts showing world distribution of geophysical operations in oil exploration and in mining are given.

3. *Geophysical Challenge.*

P. C. Ingalls, Oil & Gas J., Vol. 51, No. 28, pp. 246-7, Nov. 17, 1952.

Very large sums of money are being spent on geophysical operations each year. This imposes a big responsibility on the geophysical industry. Incentives are needed to attract and hold, better-trained men. These incentives can only be provided by an oil industry which has the advantage of a free competitive system in which to grow.

4. *A Study in Integration of Geology and Geophysics.*

H. C. Towles, Jr., Geophysics, Vol. 17, No. 4, pp. 876-899, October, 1952.

The need for co-operation between, and integration of, geology and geophysics in the Kilgore Area, Gregg and Rusk Counties, Texas. Independent interpretations of geologic structure from regional geology and reflection seismograph surveys are presented and evaluated. An integrated interpretation utilizing the geological data to define velocity limitations for the seismic time-depth relationship is attempted and a theoretical corrected structural interpretation is presented. The following conclusions are reached:

- (1) The limitations of geologic and reflection seismograph methods do not overlap; therefore it is possible to utilize the maximum interpretation of geological data as a guide to the velocity variations which affect the seismic interpretation.
- (2) Lack of sufficient velocity information can be a serious handicap to utilization of the seismic method; therefore, every opportunity to obtain additional velocity information should be utilized.
- (3) The Kilgore area illustrates that existing seismic interpretations of structure that are in disagreement with known geologic data may often be recomputed for a correct interpretation at a small extra cost.

5. *Exploration Up.*

Oil & Gas J., Vol. 51, No. 28, p. 251, November, 1952.

Canada has 185 geophysical parties in the field: 166 seismic, 15 gravity, and 4 magnetic. Alberta has 133 crews, with 122 seismic and 11 gravity. Saskatchewan has

45 crews, with 38 seismic, 4 gravity and 3 magnetic. British Columbia has 4 crews, with 3 seismic and 1 magnetic. Manitoba has 3 seismic crews.

6. *Is Seismology the Career for You?*

R. J. Foster, *World Oil*, Vol. 135, No. 7, pp. 112-114, December, 1952.

In seismology, three positions are open to the graduate: observer, surveyor and computer. All offer high starting salaries which increase rapidly. However, the wandering nature of the profession prevents a permanent circle of friends from being cultivated by any of the man's family. To make a success of seismology as his career, they must all be adaptable to, and happy in, such circumstances of life.

7. *Paria Gulf Work started.*

Oil & Gas J., Vol. 51, No. 34, p. 147, December 29, 1952.

Geophysical work has been started in the Gulf of Paria, between Trinidad and Venezuela, by the West Indies subsidiary of Standard Oil Co. of California. The area is regarded as being very promising oil territory. No details of the work are given.

8. *Exploration Work in Mexico.*

A. G. Rojas, *Geophysics*, Vol. 18, No. 1, pp. 188-200, January, 1953.

A brief resume is given of the main problems of the different provinces of Mexico under exploration and a list of the fields discovered by *Petroleos Mexicanos*, since 1940. Geophysical methods have been responsible for location of a very large proportion of the new fields. Tables show that the amount of geophysical exploration per million barrels of oil produced is very close to that of the U.S.A.

9. *Canada's Geophysical Activity constant.*

Oil & Gas J., Vol. 51, No. 45, p. 200, March 16, 1953.

In March, 1953, there were 170 geophysical parties operating in Western Canada. Alberta had 131 seismic and 8 gravity; Saskatchewan had 18 seismic and 2 gravity; British Columbia had 9 seismic; and Manitoba had 2 seismic crews.

10. *Geophysical Prospecting.*

D. T. German-Jones, *Nature*, Vol. 171, No. 4344, pp. 202-203, Jan. 31, 1953.

At the third meeting of the E.A.E.G., held at the Stadthalle, Hannover, Dec. 3-5, 1952, twenty papers were read.

H. Linnser (Germany) described the interpretation of seismic sub-surface records by a statistical method designed to improve accuracy.

H. von Helms & H. W. Maas (Germany) described recent marine seismic observations in the Baltic sea.

H. Richard (France) demonstrated the existence of multiple reflections in certain areas marked by steep dips and faulting.

R. Koehler (Germany) described a practical example of wave-energy return by diffraction from faulted beds.

J. Schoeffler (France), and H. J. Dürbaum (Germany) read papers dealing with the improvement of seismic interpretation by taking into account the departure of the actual ray-paths from the normally assumed straight-line paths.

A. T. Dennison and F. A. Roberts (Great Britain) described an electronic device for overcoming the effects of static on seismic shot signals.

H. Baule (Germany), and E. Müller (Germany) each demonstrated a method of finding the velocity of sound waves in rock samples.

B. J. Hofman (Holland) described developments in marine gravity surveying.

V. Baranov (France), O. Rosenbach (Germany), R. Koehler & E. Wirth (Germany), and B. Kosbahn (Germany) each read papers dealing with the use of the first, second, and even higher derivatives of gravity in the interpretation of field observations.

S. Saxov (Denmark) discussed the relative values of the various derivative methods in emphasizing structural anomalies at different depths.

J. Goguel (France) described certain features of the geological interpretation of the gravity map of the Paris basin.

O. Vecchia (Italy) gave a detailed account of the regional structure of northern Italy deduced from gravity measurements.

C. Gaibar-Puertas (Spain) & E. Hoge (Belgium) described the results of magnetic investigations over the palaeozoic massif of Serpont, in Belgium.

G. Kunetz & J. Chastenet de Gery (France) considered the applications of conformal representation in the interpretation of the results of telluric current surveys.

SEISMIC — GENERAL

11. *Limitations of the Seismic Method of Mapping Faults.*

F. Romberg, *Geophysics*, Vol. 17, No. 4, pp. 827-842, October, 1952.

The limitations inherent in the seismic method of mapping faults are listed and classified. These limitations are divided into instrumental, physical, and geological. An attempt is made to treat them quantitatively and to find places where the accuracy of the seismic method can, or cannot, be improved in the foreseeable future. Attention is called to the fundamental assumptions of seismic prospecting, the prevalence in practice of contradictions of these, the inability of present methods to do what is expected of them, and the difficulty of checking their results. The role of non-structural prospecting is considered, on the basis of specific failures in current methods. A general equation for dealing with horizontal velocity changes is suggested in an appendix.

12. *The Application of the Reflection Seismograph to Near-surface Exploration.*

C. F. Allen, L. V. Lombardi, & W. M. Wells, *Geophysics*, Vol. 17, No. 4, pp. 859-866, October, 1952.

The geophysical approach to very shallow exploration problems has been limited in the main to electrical, magnetic, electromagnetic, and refraction methods. The reflection seismograph, with its clear advantages of decreased ambiguity and increased resolving power, can be applied to many of these problems.

In the fall of 1951, a Stanford Research Institute crew conducted an experimental reflection survey in Minnesota, mapping with correlation spreads the glacial drift-bedrock interface along seventy miles of line. The interface varied from a few hundred feet to several hundred feet in depth below surface, and control core holes showed the seismic profile to be essentially correct, where checked. Special instrumentation included a high speed camera and a filter peaked at 100 cps. All shots were fired in the air.

The method has obvious applications to mining, engineering, and groundwater problems, and to difficult weathering problems involving thick alluvial, eolian, or glacial debris.

13. *The Inadequacy of the Standard Seismic Techniques for Shallow Surveying.*

F. F. Evison, *Geophysics*, Vol. 17, No. 4, pp. 867-875, October, 1952.

The seismic method in geophysics has been very thoroughly applied to prospecting for oil, but the techniques developed are not well suited to shallow surveying. A typical shallow survey is described to illustrate some of the shortcomings of the standard seismic techniques in this sphere. A full critique reveals both practical and fundamental limitations, the origin of most of which may be traced to the explosive source. Published data on the form of the explosive impulse suggest that it is inherently unsuitable for shallow surveying. The electromechanical source promises to overcome this difficulty by providing an impulse having any desired frequency and duration.

14. *Offshore Surveys excite Oil Operators.*
R. Sneddon, Petroleum Engineer, Vol. 25, No. 1, pp. B68-74, Jan. 1953.
A big seismic program is being carried out over the offshore region of Southern California. In open water, slow burning charges of about 90 lbs. are used to minimize the destruction of marine life. When close to shore or in shallow water, charges of about 40 lbs. are jetted into the ocean floor to a depth of at least 15 feet. The seismometers are designed to remain upright in water, so that they catch all the upcoming energy. Some of the problems of surveying and interpretation are discussed.
15. *Geological Results of several recent Reflection Seismograph Profiles obtained in Germany* (In French).
Krey, Roepke & Wendt, a paper read at the 19th International Geological Congress, at Algiers, Sept. 1952, (not yet published).
Recent results obtained by the reflection method are discussed with their geological interpretation.
16. *Core Hole Velocity Surveys.*
R. Brewer & J. B. H. Henderson, a paper read at the 6th Annual Midwestern meeting of the S.E.G., at Fort Worth, Texas, Nov. 1952, (not yet published).
A method for conducting velocity surveys in exploratory core holes is described, and results from surveys in North Louisiana, South Arkansas, and North Dakota are discussed.

17. *Seismic Exploration of Reefs.*
F. McQueen Rozelle, World Oil, Vol. 134, No. 7, pp. 83-88, June, 1952.
Nearly all recent reef discoveries have been due partially to reflection surveys. This paper presents basic considerations applied to the highly specialized problem of locating limestone reefs. The discussion includes: reef definition, geologic conditions favouring formation, lithological and structural characteristics, the effects of reef lithology and structure on seismic data, methods of interpreting and recognizing these effects, and field methods and procedures. Special emphasis is placed on interpretation.

SEISMIC — INSTRUMENTAL

18. *The design of Electromagnetic Geophones.*
A. T. Dennison, Geophysical Prospecting, Vol. 1, No. 1, pp. 3-28, March, 1953.
This paper summarizes and extends the published information on the theoretical design of electromagnetic geophones. Both moving-coil and moving-armature instruments are considered, their behaviour compared and various design criteria established.
19. *An Electromechanical Transducer System for the Transient Testing of Seismographs.*
P. M. Honnell, Geophysics, Vol. 18, No. 1, pp. 160-187, January, 1953.
This paper describes the theory and construction of an electromechanical transducer system which reproduces vertical mechanical motions in the image of arbitrarily specified waveforms for the transient testing of seismographs. Results of such tests on commercial seismometers are included.
20. *Patents.*
Abstracts in Geophysics, Vol. 18, No. 1, p. 226, Jan. 1953.
U.S. Re.23,552. 30 Sept. 1952. A marine seismometer layout.
U.S. 2,604,955. 29 July 1952. System for analyzing seismic records.
U.S. 2,607,842. 19 Aug. 1952. A marine seismometer layout.
U.S. 2,609,438. 2 Sept. 1952. Radio system for seismic recording.

- U.S. 2,609,885. 9 Sept. 1952. Explosive for seismic prospecting.
 U.S. 2,610,240. 9 Sept. 1952. A marine seismometer layout.
 U.S. 2,611,024. 16 Sept. 1952. Multi-channel seismic amplifier.
 U.S. 2,612,568. 30 Sept. 1952. An avc system for seismic amplifiers.

21. *Modern Changes Aid Efficiency of Seismographic Equipment.*

D. G. O'Brien, *World Petroleum*, Vol. 24, No. 3, pp. 70-72, March, 1953.

Geophysical equipment to-day is doing a far better job under more difficult conditions, than did the equipment of several years ago. Modern design has greatly reduced the size of instruments and units, but their versatility has been improved by several times.

SEISMIC — INTERPRETATION

22. *The Significance of Diffraction in the Investigation of Faults.*

T. Krey, *Geophysics*, Vol. 17, No. 4, pp. 843-858, October, 1952.

Seismic reflection records taken across faults frequently show an overlapping of reflections from the displaced blocks. It is demonstrated that diffraction of seismic waves is a cause and the effect may be used in interpretation. Overlapping is increased if a seismic profile crosses a fault at an acute angle. Plotted dips will be inaccurate unless diffraction is taken into account. Further, the diffraction oscillation pattern will also be obtained if a reflection horizon terminates for a reason other than faulting, for example, at a wedgeout or reef edge, or at a sudden change of facies. The ideas developed are demonstrated by practical examples in which attention is directed to the approximations involved in plotting the boundaries of discontinuities.

23. *A Ruler for Seismic Refraction Problems.*

J. Goguel, *Geophysical Prospecting*, Vol. 1, No. 1, pp. 44-48, March, 1953.

A ruler has been constructed to solve seismic refraction problems with horizontal or slightly inclined layers.

SEISMIC — THEORY & RESEARCH

24. *Notes of the Use of Multiple Geophones.*

L. V. Lombardi, a paper read at the Pacific Coast meeting of the S.E.G., at Los Angeles, Oct. 1952, (not yet published).

The use of multiple geophones, which has been largely empirical, serves two primary functions: cancellation of random and other unwanted energies, and improved sampling of the wave front. Curves are presented showing surface wave cancellation effectiveness of several different spreads. The results also apply to mixed records. Cancellation of random energies follows conventional sampling theory, varying with the square root of the number of geophones in the spread. Sampling of the wave front is more complex because the samples are not mutually independent.

25. *Wavelet Contraction, Wavelet Expansion, and the Control of Seismic Resolution.*

N. Ricker, a paper read at the 6th Annual Mid-western meeting of the S.E.G., at Fort Worth, Texas, Nov. 1952, (not yet published).

This paper discusses the transmission characteristics of seismic apparatus for distortionless reproduction of seismic wavelets. It is shown that, by suitable design of seismic apparatus, the individual wavelets which go to make up a seismogram may be contracted or expanded without altering the relative arrival times of the wavelet centres. By means of this procedure the resolving power of the seismic apparatus may be increased or decreased at will, within certain limits. Laboratory studies of the

performance of the wavelet contractor are described and field seismograms made with the wavelet contractor are displayed.

26. *Seismic Model Study.*

E. T. Howes, L. H. Tejadaflores, & L. Randolph, a paper read at the 44th meeting of the Acoustical Soc. of America, at San Diego, Calif., Nov. 1952, (not yet published).

A model seismic reflection set-up is described. Acoustic waves are transmitted from a source to a faulted limestone stratum by way of a tank of water. The returning waves are recorded on an oscillogram. Details of the equipment used are given.

27. *A One-dimensional Seismic Wave Model.*

J. F. Evans & C. F. Hadley, a paper read at the 44th meeting of the Acoustical Soc. of America, at San Diego, Calif., Nov. 1952, (not yet published).

One-dimensional wave models have been produced from helical wire springs. Springs with contrasting acoustic impedances can be connected together, suspended horizontally, and used for experimental study of plane wave propagation problems. Means are described for introducing various forms of mechanical pulses into the model and for detecting and recording the resultant motion at any desired position along the model.

28. *Some Observations on Travelling Waves from Explosive Sources.*

P. L. Lawrence & M. B. Dobrin, a paper read at the 44th meeting of the Acoustical Soc. of America, at San Diego Calif., Nov. 1952, (not yet published).

The Delaware Basin area of West Texas is characterized by alternating high and low velocity layers near the surface, with a thin high velocity cap over most of the region investigated. The physical characteristics of waves arriving before the Rayleigh waves are discussed and correlated with the layering.

29. *Sound Waves observed in a mud-filled well after Surface Dynamite Charges.*

J. R. Ording & V. L. Redding, a paper read at the 44th meeting of the Acoustical Soc. of America, at San Diego, Calif., Nov. 1952, (not yet published).

Charges were exploded in an 80 ft. hole, 500 ft. from the heads of two mud-filled wells that were drilled below 12,000 ft. Three pressure pick-ups, 100 ft. apart and covering a vertical range of 200 ft. were used to record the waves in the wells. A separate charge was fired with the array at each 500 ft. interval in the wells. In some cases the pressure pulse travelled directly through the sedimentary rocks to the recorder. In other cases waves travelled through the mud column to the recorder.

30. *Piezoelectric Well Hydrophones.*

C. B. Vogel, a paper read at the 44th meeting of the Acoustical Soc. of America, at San Diego, Calif., Nov. 1952, (not yet published).

When measuring seismic velocity as a function of depth by exploding a charge at the surface and measuring travel-time to a detector suspended by cable within a deep well, errors often occur through vibrations transmitted along the cable or casing. Three types of piezoelectric hydrophones which eliminate these errors in deep wells and shallow holes are described and the results of field experiments are discussed.

31. *Electrokinetic Low Pressure Detectors.*

R. G. Packard, a paper read at the 44th meeting of the Acoustical Soc. of America, at San Diego, Calif., Nov. 1952, (not yet published).

Electrokinetic detectors, for detecting sinusoidal pressures of low amplitude and low frequency, have been constructed and tested. The construction of the detectors is described and response curves of frequency and amplitude are given.

32. *Oblique Multiple Reflections.*

H. Richard, *Geophysical Prospecting*, Vol. 1, No. 1, pp. 49-63, March 1953.

Examples of oblique multiple reflections are treated and possible solutions given.

33. *Gulf Coast Surface Waves.*

L. G. Howell, E. F. Neuenschwander, & A. L. Pierson III, *Geophysics*, Vol. 18, No. 1 pp. 41-53, January, 1953.

Surface wave recordings were made with the following: a three-component velocity seismometer, a long-period displacement seismometer, six dynamic seismometers, an air-actuated condenser microphone, and a vertical strain seismometer. Wave trains were recorded similar to those obtained by B. F. Howell in California. The surface waves were divided into two trains instead of three. The early train seemed to have properties of the M-2 wave of Sezawa; the late train seemed to be a Rayleigh wave. An air-coupled wave is shown to be associated with the M-2 wave. In the group velocity dispersion curve of the Rayleigh wave, the short-period branch was found as predicted by theory as well as the usually observed long-period branch. By making certain assumptions, the thickness of the top layer appears to be about 50 feet according to the theoretical curves of Kanai.

GRAVITY — GENERAL

34. *Gravity Measurements at sea, 1948 and 1949.*

J. L. Worzel & M. Ewing. *Trans. Amer. Geophys. Un.*, Vol. 33, No. 3, pp. 453-460, 1952.

During 1948-49, 180 observations were made in the Bahama Islands area, 118 along the east coast of the United States between Key West and Cape Hatteras, 363 in the Pacific Ocean, and 142 along the west coast of Canada, south coast of Alaska, in the Aleutian Islands, and the Bering and Chuckchi Seas.

35. *Gravimetric Base Measurements in Northeastern Poland.* (In Polish).

R. Weiladek, *Panstwowy Instyt. Geol. Biul.* 76, Ser. Geofiz. No. 7, 1951.

A report on gravimetric base determinations during 1949 in an area of about 35,000 sq. km. in northeastern Poland. A Nørgaard gravimeter was used and the observatory of the Polish geologic institute served as a base station. Sixty-six stations were occupied. Bouguer anomalies were computed and a map of isoanomalies constructed. A detailed description of the Nørgaard gravimeter and its operation is included.

36. *Contribution to the construction of the Gravimetric Map of Italy, 1st loop.* (In Italian).

Boaga, Giovanni, Tribalto & Zaccara, *Servizio Geol. Italia, Boll.*, Vol. 72, Fasc. 1, pp. 161-181, 1951.

Gravity determinations were made along three profiles, total length more than 800 km., from the base station Rome to Bologna. Sixty-two stations were occupied at altitudes of 3 to 600 m. above sea level, and with gravity differences between -72 and +67 mgal. Tables of the Faye and Bouguer anomalies are given. For the latter, densities from 1.6 to 2.5 were assumed in accordance with data from the recently published geologic map of Italy.

Comparison of these results with those of previous determinations of gravity indicates that the Western gravimeter is well adapted to relative gravity measurements.

37. *Contribution to the construction of the Gravimetric Map of Italy, 2nd loop.* (In Italian).

Boaga, Giovanni, Tribalto & Zaccara, *Servizio Geol. Italia, Boll.*, Vol. 72, Fasc. 2, pp. 75-93, 1951.

Gravimetric measurements in Bari province tied Rome to Naples, Bari, and Foggia, using 45 intermediate stations along 1,200 km. of profiles. Tables of the results are presented. For computation of Bouguer anomalies, density values of 1.80 to 2.40 were taken from the recently published geological map of Italy.

GRAVITY — INSTRUMENTAL

38. *Patents.* Abstracts in Geophysics, Vol. 17, No. 2, p. 395, April, 1952.
U.S. 2,570,659. 9th October, 1951. Borehole Gravity Meter.
U.S. 2,574,395. 6th November, 1951. Torsion Balance Device.
39. *Patents.* Abstracts in Geophysics, Vol. 17, No. 3, p. 626, July, 1952.
U.S. 2,589,709. 18th March, 1952. Gravimeter.
U.S. 2,589,710. 18th March, 1952. Gravimeter.
U.S. 2,590,740. 25th March, 1952. Gravimeter.
40. *Patents.* Abstracts in Geophysics, Vol. 17, No. 4, p. 951, October, 1952.
U.S. 2,595,092. 29th April, 1952. Condenser-type gravimeter for underwater surveying
41. *Patents.* Abstracts in Geophysics, Vol. 18, No. 1, p. 225, January, 1953.
U.S. 2,610,507. 16th September 1952. Gravimeter.

GRAVITY — INTERPRETATION

42. *The Gravitational Attraction of a deposit of clay.*
A. H. Cook, Mon. Not. Roy. Astronom. Soc., Geophys. Suppl., Vol. 6, No. 5, May 1952.
On the basis of the study of clays made by Skempton (1944) and others, estimates have been made of the gravitational attraction of a deposit of clay. Examples of the behaviour of some typical clays are given and a procedure for correcting gravity anomalies for the attraction of a deposit of clay is suggested.
43. *A Nomogram for the computation of Tidal Deviations of the Vertical.*
A. B. Malone, Geophysics, Vol. 17, No. 3, pp. 615-619, July, 1952.
It is possible to adapt a nomogram, devised by T. A. Elkins, for the computation of tidal variations in the vertical component of the earth's gravitational field, to the computation of tidal deviations of the vertical. The nomogram is explained and illustrated and a worked example given.
44. *Some remarks on the interpretation of Gravitational and Magnetic Anomalies.*
K. Jung, Geophysical Prospecting, Vol. 1, No. 1, pp. 29-35, March, 1953.
Two geometric methods are given: one for estimating the position of mass distributions from the gravity anomalies, the other for determining the position of a thin plate of magnetised material from the magnetic anomalies. Finally a computational form of Nettleton's method for the determination of density is given.
45. *Principle of Direct Interpretation Methods in Gravimetric and Magnetism.*
B. Farre & R. Dalby, Rev. Inst. Franc. Petr., Vol. 7, No. 7, pp. 217-234, 1952.
The indirect classical methods for interpreting the potential field observed at the surface of the earth usually involve the assumption of a mass distribution for which the effects are calculated, and this distribution is progressively modified until a close fit with the observations is obtained. In the method discussed, the observed field is continued downwards by analytical means so as to approach the actual structure; and this involves the calculation of the successive derivatives of the vertical component of the field. The mathematical basis of the method is indicated, and diagrams illustrate the comparative closeness with which the second derivatives reveal the geological features when the anomalies are well defined.

GRAVITY — THEORY & RESEARCH

46. *Gravity Anomalies and Deflections of the Vertical above Sea Level.*

R. A. Hirvonen, Trans. Amer. Geophys. Un., Vol. 33, No. 6, pp. 801-809, Dec., 1952.

By the aid of Poisson's integral formula, the gravity anomalies, the potential of the disturbing masses, and the deflections of the vertical above sea level can be computed if the gravity anomalies at sea level are known. This means a generalization of the well known formulae of Stokes and Vening Meinesz. Some practical applications on the basis of presently available gravity observations are given.

47. *Three Dimensional interpretation of Gravitational Anomalies, Part II.*

F. S. Grant, Geophysics, Vol. 17, No. 4, pp. 756-789, October, 1952.

This is the second of two papers describing a method of interpreting residual gravitational anomalies in terms of three-dimensional geologic structures. This paper describes an analytical method for smoothing the data, and for constructing charts and templates for computing derivatives and other quantities required in the interpretation formulae already given in Part I. Tables of all quantities required for the practical utilization of this procedure are provided. Two examples of the application of these methods are given: the first, an artificial problem, and the second, an actual survey conducted over a sulphide body that has been outlined by extensive drilling.

MAGNETIC — GENERAL

48. *The significance of Aeromagnetic Data.*

H. S. Scott, Precambrian, Pt. 1, Vol. 25, No. 6, pp. 7-9, 33-34;

Pt. 2, Vol. 25, No. 7, pp. 21-25, 1952.

A general review of the magnetometer, especially the airborne magnetometer, in exploration. Examples from total-intensity surveys are used to illustrate the main points of discussion.

49. *Air Surveys Speed Canadian Exploration.*

T. M. O'Malley, Petroleum Engineer, Vol. 25, No. 2, pp. B. 78-84, February, 1953.

More than 100,000 sq. mls. are now being explored, with 5 airborne magnetometers, in N.W. Canada. The surveys will be much more detailed than the 1950-51 Peace River Survey. Photo flight-maps guide the survey planes. Weather, the worst problem, causes many costly delays. The remoteness of the area necessitates a large store of spare parts kept at hand. Field results are flown to Ottawa where they are usually compiled into magnetic intensity maps with contour intervals of 10 gammas.

MAGNETIC — INSTRUMENTAL

50. *Patents.* Abstracts in Geophysics, Vol. 17, No. 2, p. 396, April, 1952.

U.S. 2,570,870. 9th October, 1951. Electrical bridge compensation for a magnetometer.

51. *Patents.* Abstracts in Geophysics, Vol. 17, No. 3, p. 627, July, 1952.

U.S. 2,584,571. 5th February, 1952. A self-oriented total-field magnetometer.

U.S. 2,590,184. 25th March, 1952. A Balance-type Magnetometer.

52. *Patents.* Abstracts in Geophysics, Vol. 17, No. 4, p. 951, October, 1952.

U.S. 2,590,979. 1st April, 1952. Magnetometer.

U.S. 2,598,284. 27th May, 1952. Magnetometer, Flux-gate Type.

U.S. 2,598,285. 27th May, 1952. Magnetometer, Flux-gate Type.

U.S. 2,599,687. 10th June, 1952. Borehole Magnetometer.

MAGNETIC — INTERPRETATION

53. *Improved Magnetic Method can avoid Drilling Failures.*

M. Milstein, *World Oil*, Vol. 136, No. 1, pp. 87-89, January, 1953.

An improved method of interpreting magnetic data, in which the observed vertical intensity curves are analysed step by step and correlated with the stratigraphic and structural pattern of the area.

54. *Some remarks on the interpretation of Gravitational and Magnetic Anomalies.*

K. Jung, *Geophysical Prospecting*, Vol. 1, No. 1, pp. 29-35, March, 1953.

Two geometric methods are given: one for estimating the position of mass distributions from the gravity anomalies, the other for determining the position of a thin plate of magnetized material from the magnetic anomalies. Finally a computational form of Nettleton's method for the determination of density is given.

MAGNETIC — THEORY & RESEARCH

55. *Magnetic Susceptibility Measurements in Minnesota.*

(Part 1: Technique of Measurement).

H. M. Mooney, *Geophysics*, Vol. 17, No. 3, pp. 531-543, July, 1952.

Susceptibility determinations have been made on 200 outcrops of 11 rock types, using a three-coil induction instrument. Measurement is effective over a hemisphere of 50 cm. radius. Data are given to show that the instrument is much less sensitive to rock surface irregularities than any previously described. Measuring circuits consist of 975 cycle oscillator, mutual inductance bridge, and two-stage amplifier. Investigation of errors shows that surface irregularities remain most important. Calibration by calculation is checked against ferric chloride standards through small samples taken at each outcrop. Data are given to show: 1) rock variability makes the check inconclusive, 2) variation of susceptibility within outcrops for gabbro and basalt is of the same order as variation between outcrops, 3) small-sample measurements show greater variation than large-sample measurements.

ELECTRICAL

56. *Electrical Resistivity Method with direct current in Geophysical Explorations.*

(In Polish).

Z. Malkowski, *Panstwowy Instytut. Geol. Biul.* 63, Ser. Geofiz. No. 6, pp. 5-31, 1951.

The physical basis and interpretation of results in electrical resistivity prospecting are discussed in detail. Roman's tables are recommended for interpretations.

57. *Description of instruments in Geophysical Exploration by Resistivity Method.*

(In Polish).

J. Uchman & Z. Sobieski, *Panstwowy Instytut. Geol. Biul.* 63, Ser. Geofiz. No. 6, pp. 33-38, 1951.

A description is given of instruments and apparatus used in electrical resistivity measurements and in electrical logging by the Schlumberger method.

58. *The interpretation of Electromagnetic Reflection Data in Geophysical Exploration. Part I, General Theory.*

W. J. Yost, *Geophysics*, Vol. 17, No. 1, pp. 89-106, January, 1952.

It is shown that any variable current method of electrical exploration must be interpreted in terms of a semi-infinite conducting medium underlying a semi-infinite insulator. The complete theoretical treatment for a homogeneous conductor is outlined, and the details of the solution for low frequencies are presented. These indicate that the

measured field intensities are not in-phase with the exciting current, as has previously been assumed. These out-of-phase components from a homogeneous earth complicate the desired interpretation in terms of resistivity discontinuities at depth. The results of this paper provide a means of suitably correcting for this factor. Secondly, the insulating (air) region is shown to have an influence on the electromagnetic fields within the conductor. Thus, when considering the image approximation, the images are influenced by the air region and cannot be assumed to behave as they would in an infinite conductor. The lack of validity of this earlier assumption is demonstrated and suitable correction factors are derived. Specific results for the two cases of most practical interest are presented in graphical form. These are compared with experimental data obtained from a laboratory scaled model composed of metallic plates.

59. *Patents.* Abstracts in Geophysics, Vol. 17, No. 3, p. 626, July, 1952.
 U.S. 2,581,349. 8th January, 1952. Method of Electrical Prospecting using Radio Waves.
 U.S. 2,585,907. 19th February, 1952. Transmitting and Receiving Apparatus for Electromagnetic Prospecting.
 U.S. 2,586, 667. 19th February, 1952. Method of Electrical Prospecting using Tellural Currents.

60. *The applications of Multiple Frequency Electromagnetic Exploration to Mining.*
 S. H. Ward, a paper read at the Eastern Canada Meeting of the S.E.G., a Toronto, Ontario, October, 1952. (Not yet published).
 A variable frequency electromagnetic exploration technique has been devised which, theoretically, will provide information concerning the physical properties and dimensions of buried conductors of electricity. A field test showed that information regarding dip, depth, plunge, and electrical conductivity was much more reliable than that obtained by other geophysical techniques. Another test showed that the new method would make reliable estimates of percentage iron in a magnetic deposit. Other possible applications are discussed.

61. *Five years of Electrical Prospecting in connection with Hydrological Investigations in North Africa.*
 J. J. Breusse, a paper read at the 19th International Geological Congress, at Algiers, Algeria, September, 1952, (not yet published).
 A map giving the statistics for North Africa shows the geographical locations of the hydrological studies. A summary tabulates the number and duration of the prospects performed until December 31st, 1951, for Tunis, Algeria and Morocco. The data from the problems investigated in these three areas are given. A typical example is given for each area showing the results of the geophysical investigations together with the results obtained from subsequent drilling.
 Results of these surveys prove the value of geophysics in prospecting for water, and will influence its use in the future.

62. *The interpretation of Electromagnetic Reflection Data in Geophysical Exploration.* Part II — Metallic model experiments.
 W. J. Yost & Colleagues, Geophysics, Vol. 17, No. 4, pp. 806-826, October, 1952.
 A metallic model of a horizontally stratified section of the earth's crust has been constructed to provide information of considerable value in the interpretation of geophysical data. Modelling considerations and experimental arrangements are discussed in detail for a system employing loops of wire as transmitter and receiver for the study of propagation of electromagnetic energy in and on a semi-infinite conductor. An experimental check of the theory given in Part I has been made for the case of a semi-infinite conducting medium underlying a semi-infinite insulator. Discontinuities

in electrical conductivity within such a medium have been shown to reflect electromagnetic pulses back to the surface. A detailed study of the shape of these pulses from single reflectors has been made showing that certain characteristics of the pulse shape can be correlated with the depth and nature of the reflecting horizon. The reflected signals can be approximately described by considering the discontinuities as reflectors which, in turn, can be replaced by virtual "image" oscillators in a homogeneous structure. The extent to which this approximation holds is discussed in the light of experiments with the model. An example is given of the use of a non-concentric loop arrangement for geophysical profiling of a limited reflector, such as a salt dome. Finally, data are given to show the agreement between model signals and field results obtained from a known resistivity contrast in the earth.

GEOCHEMICAL

63. *Patents.* Abstracts in Geophysics, Vol. 17, No. 3, p. 626, July, 1952.
U.S. 2,590,113. 25th March, 1952. A Soil Analysis Prospecting Method.

64. *Research on Geochemical Well-logging.*

E. Vellinger, Rev. Inst. Franc. Petr., Vol. 7, No. 7, pp. 239-249, 1952.

By geochemical well-logging it is hoped to gain information on the existence of oil in the neighbourhood of the well. Traces of hydrocarbons absorbed in the rocks are sought. The gas from cuttings and cores is analysed, and it is found that as the reservoir rock is approached the amount of hydrocarbons rises rapidly.

65. *A review of American Progress in Geochemical Prospecting, and recommendations for future British work in this field.*

J. S. Webb, Bull. Inst. Min. & Metal., Vol. 62, Pt. 7, No. 557, pp. 321-348, April, 1953.

American achievement in geochemical prospecting for metallic deposits and ores is reviewed. Soil analysis, now a standard practice in some districts, has been successful in locating sub-outcropping minerals. In America and Canada, 15 mining companies are exploring by geochemical methods which have assisted in the discovery of at least two commercial base-metal deposits. Extensions of known orebodies have also been traced by these methods.

The author outlines a plan for critical geochemical prospecting in British territory with a view to the long-term need for new mineral resources. The work would provide the mining industry with additional methods of exploration, particularly applicable in difficult tropical terrain.

A PROCESS OF SEISMIC REFLECTION INTERPRETATION *

BY

J. G. HAGEDOORN **

ABSTRACT

A process is described whereby the interpretation of seismic reflection data is carried out by a preliminary two-dimensional plotting procedure followed by a three-dimensional migration. The concept of a surface of maximum convexity is introduced as an integral part of the process of migration. The procedures for deriving the necessary charts of curves are considered and a number of serviceable charts presented.

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* Thesis, University of Utrecht, Holland, May 24, 1954.

** N.V. de Bataafsche Petroleum Maatschappij, The Hague.

INTRODUCTION

Interpretations of physical phenomena are almost always carried out by processes of abstraction by which pertinent data are reduced to those essentials which admit of mathematical treatment. The extent to which such reductions are permissible is conditioned by the accuracy required of the results to be obtained, which accuracy is limited by the reliability of the data upon which one has to work.

Both the more theoretical and the more practical seismologists aim to simplify their interpretational methods, the former in order to be able to use the mathematical tools at his disposal while the latter does so to achieve fast routine methods. The three main criteria by which the relative values of different interpretational methods must be judged are reliability, speed and clarity. A critical analysis of the existing interpretational methods, as laid down in textbooks (Nettleton, Dix³, etc.) and publications (Geophysics, etc.) and further adapted to routine work by the practicians, obviously does not fall within the scope of this thesis. It might even seem superfluous to wish to add yet a new line of thought to these established methods which have already led to so many satisfactory results in practice. The method introduced in this thesis, however, brings forward some new concepts which may lead to an improvement in reliability and speed in interpretation. Furthermore, an almost purely geometrical line of thought is followed which may appeal, particularly, to the less analytically minded geophysicists.

As already done, for example, by Thornburgh and Riznichenko, the concept wavefront is taken as the point of departure and not the concept trajectory as is done in most methods. Choice of either concept depends, naturally, upon the way in which the abstractions wavefront and trajectory are formulated and are to be used. A general picture of the manner in which a seismic wave is propagated can be obtained by briefly considering the physical conditions, and at the same time an idea is gained of the degree of vagueness of the concepts wavefront and trajectory.

In geometrical optics the concept of a trajectory or ray as a narrow beam along which energy is transported has a visual and physical significance because long series of waves, with wavelengths in the order of fractions of a thousandth of a millimeter, are involved. Only when the dimensions involved in optical research are in this same small order of magnitude, as in microscopy, do complications like diffraction arise.

In the usual seismic work, however, the energy is transported in the form of a short compressional wavelet which does not change its form very rapidly as it travels along. In its simplest form (Dix^{1, 2}, Ricker) it will roughly resemble the one illustrated in fig. 1. A compression is followed by a rarefaction and not much else. In reflection work, where such a pulse is registered against a background of disturbance of the same order of magnitude, it may

be the first compression from A to B with its peak at P which is observed in practice when only a small amount of filtering is applied.

Even for such a short pulse it is possible to speak of a wavelength and a frequency in a very broad sense. Analogous to the principle of Huygens-Fresnel, an energy quantum from the source S in fig. 2 can contribute to the first compression received in R if its trajectory does not exceed the minimum path by more than a half wavelength, corresponding roughly to the distance from A to B in fig. 1. From these considerations the order of magnitude of the width of the beam between source and receiver can be evaluated in the manner shown in fig. 2. Within the usual range of distances, velocities and frequencies

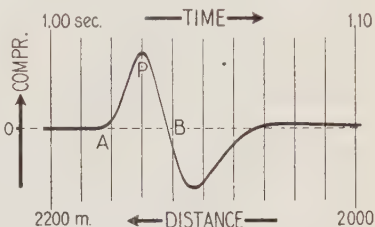
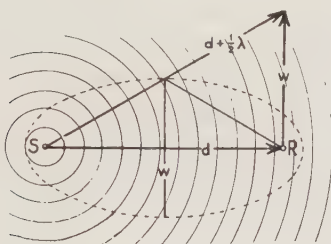


Fig. 1. A simple type of waveform from a seismic shot.



$$d^2 + w^2 = (d + \frac{1}{2} \lambda)^2 = d^2 + d \lambda + \frac{1}{4} \lambda^2$$

$$w \approx \sqrt{d \lambda}$$

distance: d from	500	to	10000	m.
velocity: V	1000	"	6000	m/sec.
frequency: n	10	"	100	cycles/sec.
wavelength: $\lambda = V/n$	10	"	600	m.
width: w	70	"	2500	m.

Fig. 2. The width of a beam between shotpoint and receiver for the practical magnitudes of distance and frequency.

encountered in seismic work, it is clear that it is quite impossible to speak of trajectories in a physical sense of narrow beams.

On the other hand a wavefront, the front surface of the wave travelling away from the explosive source at a certain moment, can be physically visualized and is determined within relatively narrow limits. In reflection work where, in contrast to refraction work, the first compression is observed, at P in figure 1, the wavefront must be defined as the surface to which this first peak has travelled and this surface is also well defined physically. This can be illustrated by dropping a pebble into a pond. The wave with its front, first peak and following troughs and peaks can be seen travelling outwards but trajectories are not seen. This illustration, even though referring to a two-dimensional transverse wave, more closely resembles a seismic occurrence than any analogy from geometrical optics where it is fundamentally impossible for the eye to follow wavefronts moving with the speed of light.

In seismic interpretation a trajectory or ray can only be visualized as a mathematical abstraction, either as the line between source and receiver along

which the traveltime is a minimum, or, except in case of anisotropy, as the line perpendicular to the wavefront at each intermediate time.

It must be borne in mind that the frequency range, as referred to in fig. 2, with its associated broad beam, is the only part of the sonic spectrum which, in practice, could be expected to give rise to observable reflections over the distances involved. This is due to the high degree of inhomogeneity of the transmitting earth material as compared, for example, with the atmosphere and water. The smaller the samples within which velocities are measured, the larger will be the variation in velocities found. Even when determining velocities in samples measuring a few inches (Baule), which is large compared to the size of individual grains, astonishingly large variations are found. Because of the levelling effect, due to the energy between source and receiver having travelled in a broad beam, the overall impression of the medium is one of homogeneity for which the conception of a wavelet travelling along without changing its form or being scattered too rapidly becomes possible. The longer the wavelengths the greater is the levelling effect, and the smaller is the scattering creating the background of disturbance against which a reflection must be observed. On the other hand the wavelengths must be short enough to enable determination, within reasonable limits, of the location of a reflector.

Figure 3 is an idealized picture of the extents of the regions involved when a reflection time is measured. It is clear that also a certain volume of the reflector, to depths of penetration of roughly one quarter of the wavelengths, is involved in the time measurement. This volume introduces a fundamental uncertainty in the location of the reflector even when data are obtained at a number of closely spaced receivers.

From these considerations it is understandable, as was also pointed out by Clewell and Simon, why the frequencies used in seismic work must lie in the frequency range of roughly 10 to 100 cycles/sec, if seismic reflections are to be obtained at all. It must be considered a stroke of fortune that, under favourable circumstances, the possibility of observing reflections actually lies within the borderline of perceptibility.

The simplifications and approximations assumed in this thesis are the usual ones which are applied as a rule in most of the seismic interpretational methods used in routine work. The media in which the seismic pulses travel are taken to be sufficiently homogeneous so that the velocity of the wavefront does not change appreciably with lapse of time or on account of change of frequency content. The velocity is assumed to be a function of depth only, thereby excluding anisotropy and appreciable lateral changes over short distances.

It must be clearly realized that these simplifications are not applied only for the sake of brevity or to arrive at a simple method adapted to fast routine work. It is not so very difficult to treat cases involving changes in velocity, other than as a function of depth, theoretically. But it is very seldom that these complications can actually be evaluated or even recognized from the data obtained in practice (Hagedoorn), to make it possible to take their influence into

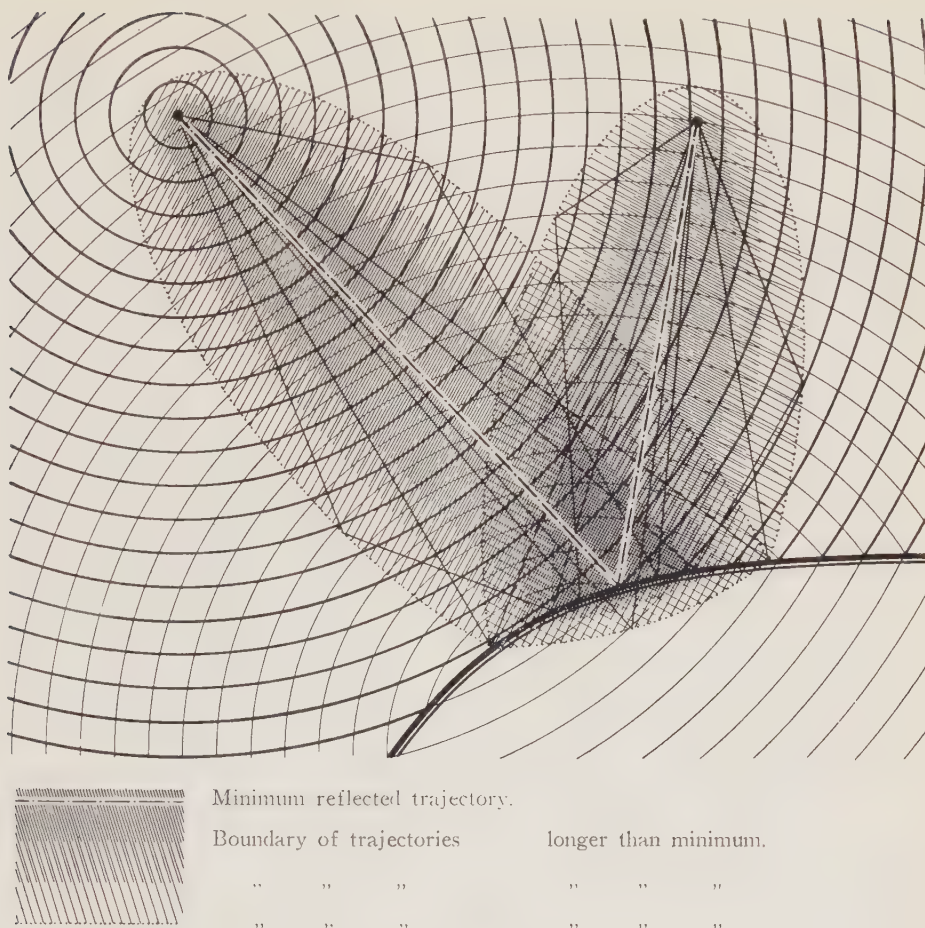


Fig. 3. Volume involved when a reflection time is measured.

account. The possibility that complications leading to grave errors may exist must always be borne in mind, but there is no sense in assuming their presence, without tangible evidence, when carrying out a routine exploration program, where a balance between speed and reliability must be maintained.

I. SURFACES OF EQUAL REFLECTION TIME AND SURFACES OF MAXIMUM CONVEXITY

1. *Vertical plotting determines the surfaces of equal reflection time.*

In fig. 4 a vertical section has been drawn through a shotpoint S and one receiver of reflected energy R, together with the intersections with a set of

wavefront surfaces centred at S and a set centred at R, both spaced at equal time intervals. A reflection time of $2T$ seconds, observed at R, will refer to a reflection from a surface that can be tangential, according to the principle of Fermat, at any point to a surface of equal reflection times consisting of the lines of intersection between wavefront surfaces at times $T + t$ from S with wavefront surfaces at times $T - t$ from R, for all values of t .

The intersection of such a surface of equal reflection times with the vertical plane through S and R is shown in figure 4 as the line through P and Q. The "point" of reflection, the point where the actual reflecting surface is tangential to the surface of equal reflection times, will, however, most probably

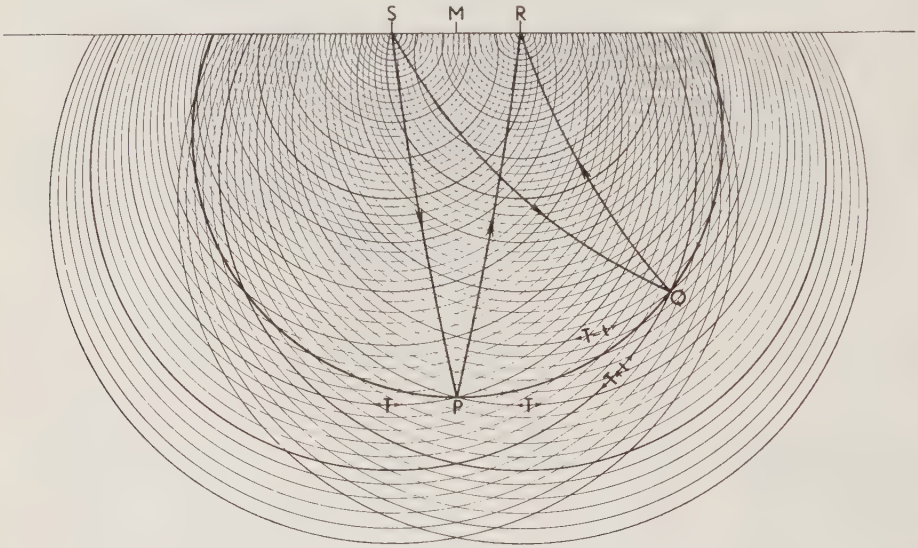


Fig. 4. One single reflection time value determines a surface of equal reflection times.

not lie in this particular plane of drawing. The orientation of one small area of the reflector in space can only be determined, in principle, by at least three surfaces of equal reflection times, found by obtaining the reflection times at at least three receivers located close together at the surface of the ground.

A surface of equal reflection times is, of course, primarily determined by the location of the actual reflector and the location of the shotpoint S and the receiver R. As the position of the reflector is, however, not yet known from one single observation, the surface of equal reflection times must be determined from the one observed reflection time $2T$, but it is also fully determined by any arbitrary point on it. The obvious point to choose is the point of symmetry P, which is also the deepest point on this surface.

It is this particular point which is plotted when the procedure called "vertical

plotting" is carried out on a two-dimensional section. In this procedure a wavefront chart with wavefront curves drawn at small equal time intervals, for example every 5 milliseconds, is centred at the shotpoint S and the point is plotted at the intersection of the interpolated wavefront curve at half the total reflection time with the vertical through M, midway between S and R. This manner of vertically plotting all time values obtained by shooting from a shotpoint to a series or "spread" of receivers is the most straightforward procedure and is very fast in practice when a wavefront chart is made available with the double times marked at the curves and with vertical lines drawn in at half the customary distances between shotpoint and receiver.

The great advantage of vertical plotting is that it can be carried out on a two-dimensional vertical section, as a first step in determining the position of the actual reflector. This is a logical consequence of the fact that a certain available number of receivers is, in practice, commonly set out in line and recorded simultaneously in order to facilitate the fieldwork and to be able to distinguish even fairly weak reflections by their correlation on a number of adjacent traces. These considerations lead to the practice of shooting seismic "lines" in preference to "patterns". However, this also leads to two-dimensional lines of interpretation, which remain quite correct only as long as vertical plotting is carried out.

It must always be clearly borne in mind that a vertically plotted point has no other significance than that of being one point determining a surface of equal reflection times, which surface is known to be tangential to the actual reflector at some point in space.

2. Surfaces of equal reflection time are surfaces of maximum concavity.

"Migration" is the procedure of determining the true reflecting surface from a surface determined by a number of vertically plotted points. This true surface can be found, in principle, as the envelope to all surfaces of equal reflection times determined by the vertically plotted points. This is essentially a three-dimensional procedure, setting out from the usually two-dimensionally, vertically plotted points. Only in the exceptional case when the vertical section through shotpoint and receivers lies in the direction of maximum dip of the reflector, can migration be carried out in the same vertical plane as the vertical plotting. Because of its greater simplicity this circumstance is aimed at quite often in practice, but it obviously excludes, for example, the possibility of shooting on a system of intersecting lines.

In fig. 5 such a two-dimensional picture is shown, representing a vertical section perpendicular to the axis of a cylindrical trough. The concavity of this trough has been chosen so great that it is possible to locate a surface of equal reflection times tangential to this reflecting surface at two points, P and Q. The reflecting curve APMQB would result in the dot-dash line when the reflection times observed along the line XY on the surface of the earth are

vertically plotted. In most cases in actual practice only the times resulting in the parts $A'P'$ and $B'Q'$ would be observed as reflection times. The reflected impulses received from between P and Q would most probably be masked by the tail ends of the reflections received from A to P and from Q to B , as the distance between P' and M will be relatively small in most cases.

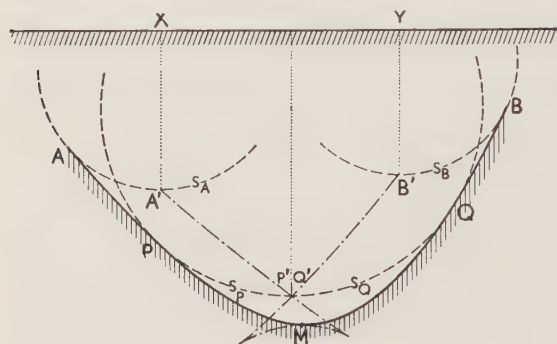


Fig. 5. A surface of equal reflection times is a surface of maximum observable concavity.

From these considerations it follows that, as a rule, a reflecting surface cannot be more concave than a surface of equal reflection times if each point is to result in a vertically plotted point or even in a relevant time observation. Consequently the surfaces of equal reflection times can be considered as the surfaces of maximum observable concavity for reflecting surfaces. A region of higher concavity can hardly ever be determined but its existence will be marked by a sharp bend upwards, at P' in figure 5, of the apparent surface found by plotting vertically.

This fundamental limitation to the interpretation is not so very important when seen from the viewpoint that in exploring for oil a culmination or "high" is the desired feature. It can, however, lead to interpretational errors in regions with poor reflections because a wrong correlation from trace to trace can quite easily be carried out across such a feature.

3. The conception of surfaces and curves of maximum convexity.

Migration is the transformation of a horizon, found by vertical plotting, to the true reflecting horizon. This can be carried out by determining the surfaces of equal reflection times, or surfaces of maximum concavity, belonging to each vertically plotted point.

Inverse migration would be the transformation of an actual reflecting surface to the apparent horizon that would have been obtained by vertically plotting the reflection times. Again, as a first step, a single reflecting point can be considered and the corresponding vertically plotted representation of this point can be determined.

In figure 6 a vertical section through a single reflecting point P has been drawn. The reflection times have been obtained from a number of pairs of shotpoint and receiver. By plotting these times vertically an apparent horizon has been obtained whose intersection with the section drawn is the curve c . This surface is determined by the fact that any point Q on this surface must

be the deepest point on a surface of equal reflection times u through P .

If, by vertically plotting, an apparent horizon were found that coincided with c in figure 6, then all points on this horizon would be migrated to the

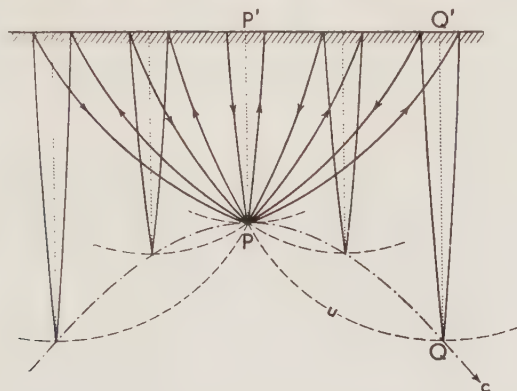


Fig. 6. A vertically plotted horizon from one reflecting point is a surface of maximum obtainable convexity.

one point P . This means that this apparent horizon from one reflecting point is a surface of maximum convexity for vertically plotted horizons.

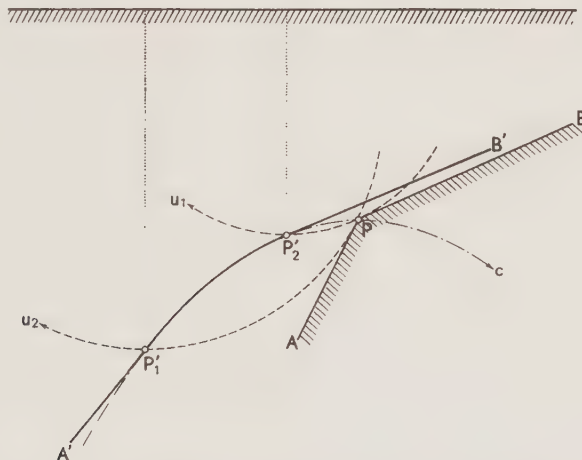


Fig. 7. An abrupt downward bend is vertically plotted as part of a curve of maximum convexity.

In fig. 7 this is illustrated on a two-dimensional section. The true horizon APB has a sharp bend at P . The part PB would be vertically plotted as $P_2'B'$ and the part AP as $A'P_1'$. Between P_1' and P_2' the vertically plotted horizon

would consist of part of the curve of maximum convexity c through P , which curve consists of the vertically plotted reflections from P .

This means that a sharp bend downwards of the reflecting horizon will show up on a vertically plotted section as a curved part, corresponding to part of a curve of maximum convexity. It would be possible to detect such sharp bends with the aid of a chart with a number of closely spaced curves of maximum convexity, by observing whether any part of a vertically plotted horizon will fit part of one of these curves.

From these considerations it is clear that there is no fundamental limitation to the interpretation when a reflector has a sharp bend downwards, in contrast to the case discussed in the preceding chapter, when a surface is more concave than a surface of equal reflection times.

4. *Observation of curves of maximum convexity in practice.*

Seen from the viewpoint that reflections must rigidly follow the laws of geometrical optics, curves of maximum convexity could not be expected in actual practice because the one point P in figure 7 would not be able to reflect any appreciable amount of energy. Reflection from one point is, however, a mathematical abstraction but the abstraction has as much significance as when a reflecting point on a smooth surface is considered. The apparent difficulties are cleared up by going back to the fundamental principles of Huygens-Fresnel in their application to seismic work, as was done in the Introduction.

The existence of these diffractions occurring at faults was also recognized by Krey. By using a method of plotting only migrated straight line segments, the essentially curved nature of these events, as can be seen on the seismograms and also when vertically plotted, was not taken into account, so that the clear picture of a curve migrating to a point was not realized. Krey worked out the mathematical problem of the energy decay as a function of distance and frequency, showing how the actual observation of these phenomena can also be explained theoretically.

Fig. 8 shows a record section obtained in Holland in 1948. The original recorded traces have been individually traced and shifted in the direction of the time axis to correct for elevation, weathering and also for the horizontal distance between shotpoint and receivers of from 300 to 600 m. This last correction to the vertical, or coincidence of shotpoint and receiver, is of course a function that varies with depth, but it can be taken to be constant in the small depth region considered in this picture.

The curved event on this vertically plotted record section can be identified, to a high degree of probability, to be a curve of maximum convexity by virtue of the fact that it can so very closely be fitted by a curve of maximum convexity. In this case a good fit is obtained by the dashed line, which is a curve of maximum convexity with its culmination at P , the point where a sharp break or bend of the reflector probably occurs.

The apparent variation of the energy along the curved event is certainly no measure of its real energy content. The automatic volume control of the recording instrument reduces the amplitude to a certain level within a certain time lag. The event will appear strong only when it is strong relative to the noise background. This means that the observed fluctuating variation in energy refers to an inverse fluctuation of the recorded noise and not, necessarily, to a variation of the energy of the event.

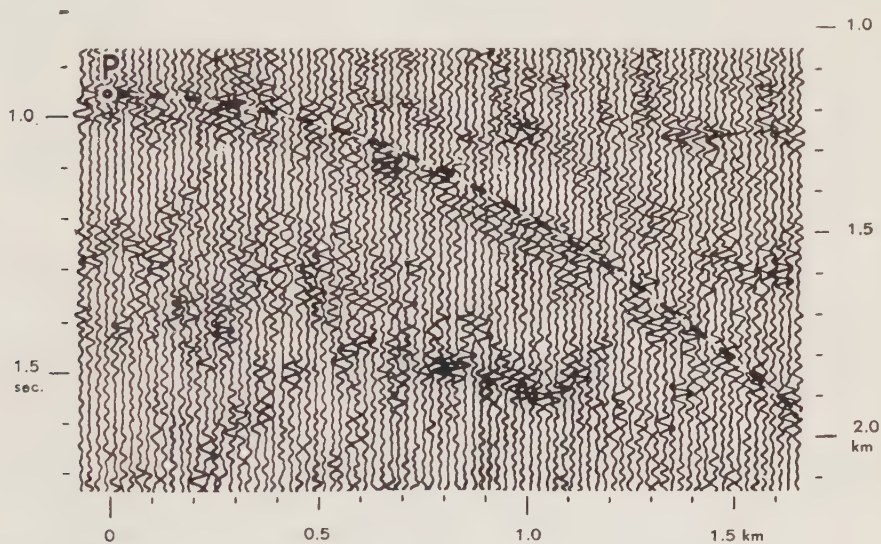


Fig. 8. A record section showing a curve of maximum convexity.

5. Relationship between a reflector and a vertically plotted surface.

In fig. 9 a stereometric picture is presented as an aid in visualizing the significance of surfaces of equal reflection times and surfaces of maximum convexity in the relationship between a vertically plotted surface and the corresponding actual reflector.

The actual reflecting point P would be vertically plotted at the axial point Q on the surface of equal reflection times, the apparently spherical surface in figure 9, which is tangential to the actual reflecting surface at P.

On the other hand the point P could be the result of any vertically plotted point on a surface of maximum convexity, the apparently hyperboloidal surface in fig. 9, with its apex at P. This surface must be tangential, at Q, to the surface that would be found by vertically plotting the results obtained from the actual reflector in the vicinity of P.

The vertically plotted point Q is the deepest point or the point on the central axis of that particular surface of equal reflection times which is tangential to the actual reflector at the particular reflecting point P. Conversely the actual reflecting point P is the highest point or the point on the axis of that particular

surface of maximum convexity which is tangential to the vertically plotted surface at the particular vertically plotted point Q .

The actual reflecting surface is the envelope to all surfaces of equal reflection times with their axial points on the surface found by vertically plotting. Conversely the vertically plotted surface is the envelope to all surfaces of maximum convexity with their axial points on the actual reflecting surface.

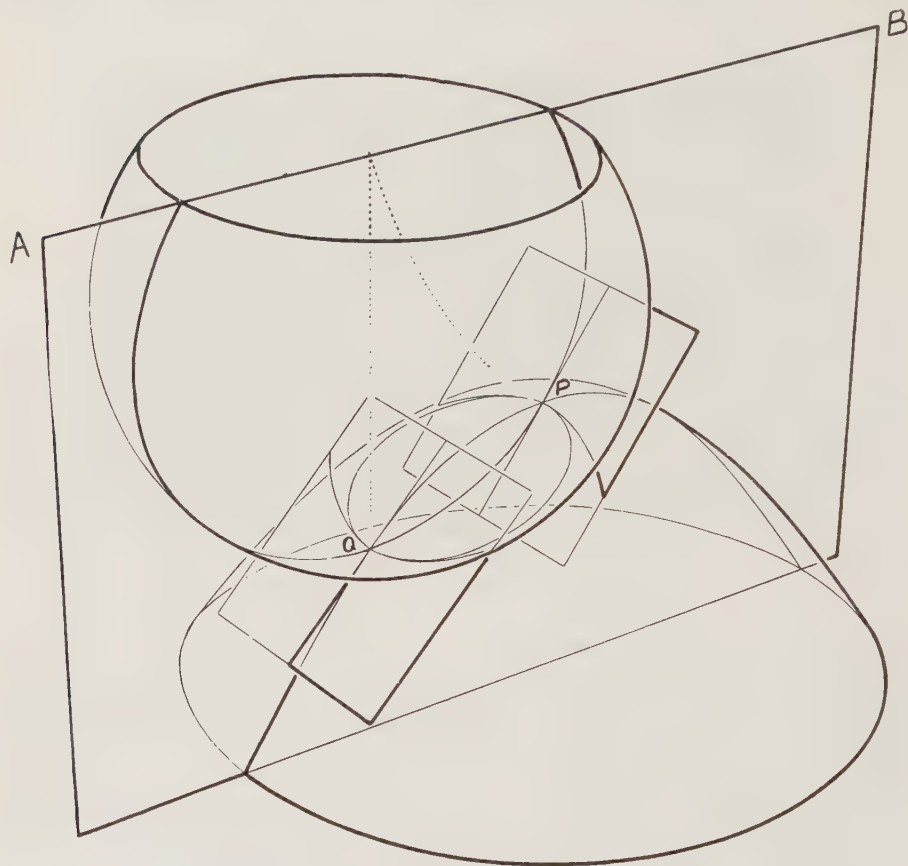


Fig. 9. The relationship between a surface of equal reflection times and a surface of maximum convexity.

Thus, the surfaces of equal reflection times and the surfaces of maximum convexity play quite analogous parts in the relationship between a vertically plotted surface and the corresponding actual reflecting surface. It is clear that a vertically plotted surface has as much fundamental significance, mathematically speaking, as an actual reflecting surface. Seen from this viewpoint it is wrong to consider it as an approximation of the actual surface, which ap-

proximation becomes better the less the surface deviates from the horizontal. The vertically plotted surface must be seen as a transformation of the actual surface with a continuous point to point relationship.

The advantage of using a vertically plotted surface, as an intermediate step in determining the actual reflector, lies in the fact that it can be determined directly point by point from the individual time measurements, either by plotting or as a record section as in fig. 8. The location of one point on this surface or its intersection with a two-dimensional vertical section through a line of shotpoints and receivers can be carried out without taking into account the orientation in space of the actual reflector. By combining a number of lines the orientation in space of the vertically plotted surface can be determined and only then can the actual surface be found by a process of transformation known as migration.

II. TWO-DIMENSIONAL MIGRATION

1. *Two-dimensional migration utilizing curves of maximum convexity.*

A vertical plane AB is shown in fig. 9, through the axis of the surface of equal reflection times and the axis of the surface of maximum convexity. Both the vertically plotted surface at Q and the actual reflecting surface at P are perpendicular to this vertical plane which lies in the direction of maximum dip of the reflector at P. By working in this plane a two-dimensional procedure of migration can be followed to determine the position of P from the position of Q.

Figure 10 is such a two-dimensional representation. It is clear that for the purpose of migration two curves are available; in the first place the curve of equal reflection times through Q with the vertical through Q as axis of symmetry and in the second place the particular curve of maximum convexity through Q which is tangential to the vertically plotted horizon through Q.

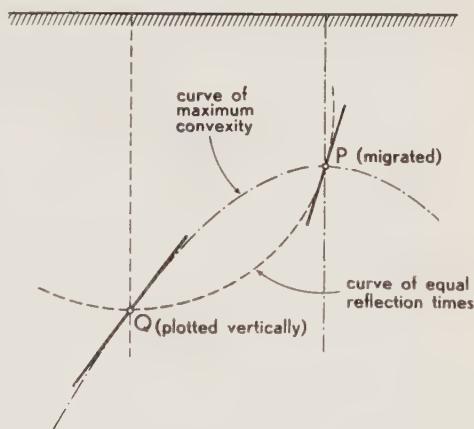


Fig. 10. Two-dimensional migration with the aid of two curves.

This leads to a practical procedure of two-dimensional migration illustrated in figure 11. A chart of curves of equal reflection times is centred on the vertical through Q and a chart of curves of maximum convexity is moved to a position where the best tangential fit to the vertically plotted horizon at Q is obtained.

Of course Q does not necessarily lie either on one of the curves of equal reflection times or on one of the curves of maximum convexity of the charts used. In practice the position of Q in regard to the adjacent curves of maximum convexity will determine an imaginary interpolated curve that can be followed to the intersection with the axis of the chart of curves of maximum convexity; this intersection P then is the migrated point. Obviously, from these considerations, the position of the migrated point P can be determined uniquely by use of the chart of curves of maximum convexity alone, because the intersection P of the curve of maximum convexity with the curve of equal reflection times through Q must lie on the central axis of the chart of curves of maximum convexity. The curve of equal reflection times through Q and P , however,

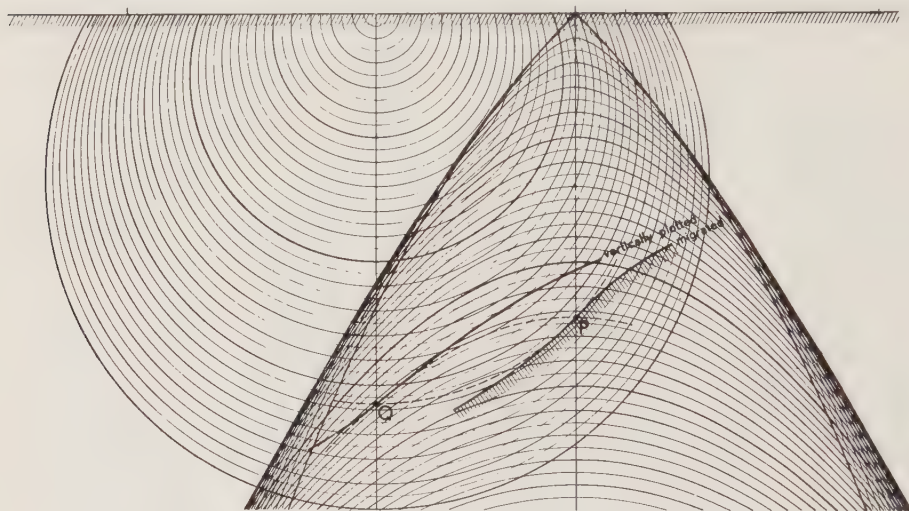


Fig. 11. Practical procedure of two-dimensional migration with the aid of two charts of curves.

determines the dip at P , for which purpose the chart of curves of equal reflection times is indispensable.

For the practical application of this method both charts must be mounted in a device which makes it possible to move them independently in a horizontal direction underneath the transparent section in such a way that the lines of zero depth on all three drawings always coincide.

2. Comparison of two-dimensional migration methods.

In practice a wide diversity of methods are in use for determining a reflecting horizon from reflection time data. Most methods are two-dimensional because

the three-dimensional methods evolved were cumbersome and time consuming. Very often plotting devices (Daly) or charts (Musgrave) are used to plot the data as a depth section in one single manipulation. These methods are based on the assumption that the location and orientation of a short length of a reflecting horizon is a function of two variables: a mean total travel time t and the change of travel time with distance, dt/dx . It can be seen that this means the determination of a curve of equal reflection times and the direction of the trajectory or the orientation of the wavefront arriving at the receivers.

The mechanical devices are, in practice, limited in their application to "straddle-shooting" and to velocity distributions linear with depth, because only in that case are wavefronts and trajectories circular (van Melle).

The use of charts is not restricted, in principle, to any particular velocity distributions. For any velocity distribution a chart could be prepared with curves of equal reflection times and curves of equal change in reflection time. These are relatively simple to make for a velocity distribution linear with depth but already fairly complicated even when other simple smooth velocity distributions can be used (Musgrave).

These last considerations would seem to apply also to the use of pairs of charts of both curves of equal reflection times and curves of maximum convexity. However, these are used after first vertically plotting the reflection points. In this procedure, shown in figure 11, the shape of the curves is the only essential consideration, whereas for plotting the horizon directly, without first plotting vertically, the time values of the curves of equal reflection times must also be correct. This imposes a stronger limitation to the possibility of using a certain smooth velocity distribution upon which to base a chart. This point will be further elaborated in chapter VI, 1.

A fundamental disadvantage of directly plotting short migrated straight line segments, is that even small uncertainties in determining changes of time with distance will result in a correlating event on a series of records no longer correlating on the section. The horizon is broken up into disconnected parts. In the extreme case where a curve of maximum convexity occurs, this will result in a concentration of short line segments at different angles. The advantage of migrating in the manner shown in fig. 11 is that a curve of maximum convexity is recognized immediately.

3. *Two-dimensional migration applied to three-dimensional cases.*

Fig. 12 is a stereometric view of two sections I and II, along which reflections are obtained from a flat reflector RAB. For the sake of simplicity it has been assumed that the velocity between the surface of the ground and the reflector is constant and that shotpoint and receiver were always coincident (normal incidence).

SP is perpendicular to the reflector and is the trajectory of the reflected impulse received at the intersection S of the two lines. The point Q, vertically

plotted below S, is the axial point on the spherical wavefront surface with its centre at S and which is tangential to the reflector RAB at P. By vertically plotting on sections I and II the apparent horizons QA and QB would be found. These must be migrated to PA and PB, which means, actually, that the depths vertically below the lines TA and TB have been determined.

It is clear that by two-dimensional migration of the apparent horizons QA and QB on the vertical sections I and II respectively, the true horizons RA and RB would certainly not be found. As the spherical wavefront through P

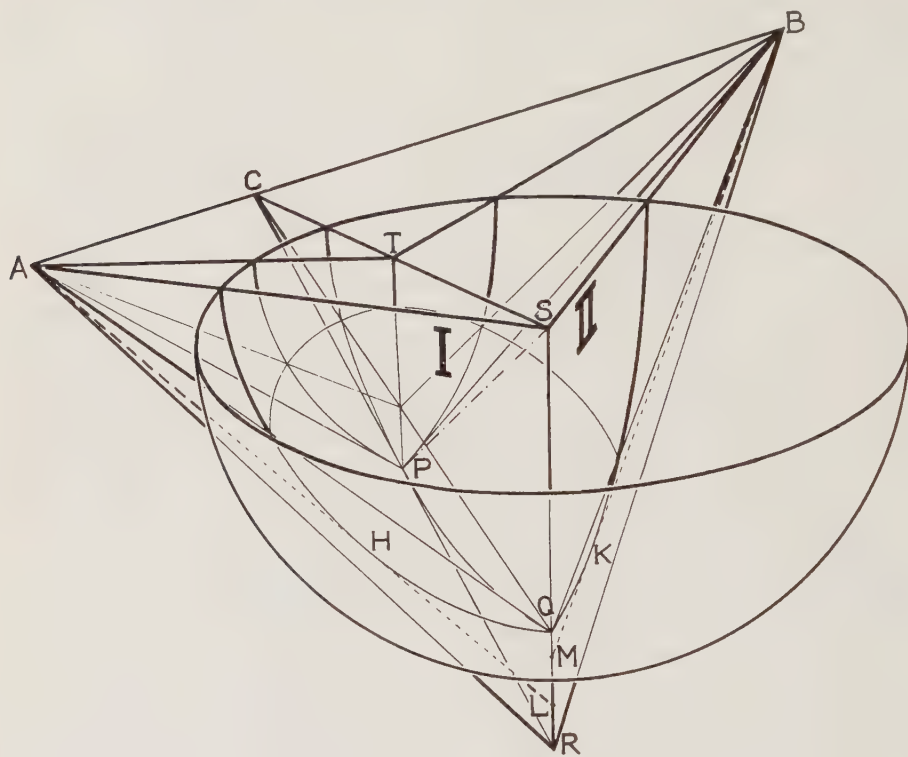


Fig. 12. Steriometric view of two intersecting seismic sections.

and with S as centre is only tangential to the true surface RAB at the one point P, the two horizons found, LA and MB, are always shallower than RA and RB, because they would be found as tangents to the circles of intersection of the sphere with the sections I and II. Furthermore, these two horizons do not cut the vertical SR at the same point, except in the symmetrical case where the two sections I and II are situated at equal angles to the direction of maximum dip CS.

Similar considerations obviously also hold when the velocity is not constant and when the reflector is not flat. It is clear that by any process of two-

dimensional migration which does not take into account the direction of maximum dip in regard to the section, horizons are found that, in general, are too shallow and which cannot be correlated at intersections of sections. In fact, the result obtained at point S in fig. 12 would be plotted at two widely different points H and K on sections I and II respectively, instead of actually at P.

Quite often, in general practice, reflection time data are plotted in their migrated position, as a matter of general routine, as though the section actually did run approximately in the direction of maximum dip, without first ascertaining whether this assumption is correct. This procedure is then defended by the assertion that the picture obtained by two-dimensional migration will be closer to reality than the picture obtained by vertical plotting alone, irrespective of the true direction of maximum dip in regard to the section. Even this belief is, however, certainly not always justified, as the procedure of automatically migrating two-dimensional sections can lead to grave errors.

If, for example, the section shown in figure 8 had been shot at an oblique angle to an edge at P, the curved horizon would have been less strongly curved, being an oblique intersection with a cylindrical surface of maximum convexity originating at the edge P. This horizon would then not migrate entirely to P by two-dimensional migration and a curved horizon extending beyond P could have been found. This "true" horizon would have no real significance but would only result in an inexplicable discrepancy when checked by actual drilling.

Strictly speaking, a horizon on a vertically plotted two-dimensional section is worthless without further evidence of its orientation in space. This further evidence can either be acquired from geological data or from cross-sections. A line shot with sufficient "cross-spreads" can give definite information, if the quality of the reflections obtained is sufficient to give reliable dip determinations over the short distances covered by the cross-spreads.

Any curved horizon, either on a vertically plotted or a migrated section should always be regarded with suspicion so long as a three-dimensional picture has not been obtained.

III. THREE-DIMENSIONAL MIGRATION WITH THE AID OF CHARTS OF CURVES

I. Migration in space visualized with the aid of families of surfaces.

Three-dimensional migration of a vertically plotted point, Q in figure 9, can be reduced to a two-dimensional migration in the vertical plane in the direction of maximum dip, the plane through A and B in figure 9. This is the procedure which has usually been followed in practice. It means, however, that a great number of auxiliary sections in the direction of maximum dip must be drawn.

Purely three-dimensional migration could be carried out, in principle, by centering a family of surfaces of equal reflection times at the vertical through a vertically plotted point Q and moving a family of surfaces of maximum

convexity to the best tangential fit to the vertically plotted horizon at that point Q . By following the surface of maximum convexity through Q to the axis of the family of surfaces of maximum convexity the migrated point P would be found. The surface of equal reflection times through Q and P would then determine the inclination of the true reflecting surface at P .

In order to be practicable, a migration method must, however, be based on a two-dimensional representation of the facts. A reflecting surface can be represented by a system of contour lines, being the projection on a horizontal datum surface of the intersection lines between the reflecting surface and a set of horizontal planes at regular depth intervals. A vertically plotted surface, represented by its contour lines would have to be migrated, in principle, with the aid of surfaces of maximum convexity and surfaces of equal reflection times also represented by their contour lines.

This is shown in fig. 13 which is the same case as shown stereometrically in fig. 9. The contour lines of the actual reflecting surface are seen to fit the contour lines of the surface of equal reflection times tangentially at P and the contour lines of the vertically plotted surface are seen to fit the contour lines of the surface of maximum convexity tangentially at Q .

This tangential coincidence of contour lines takes place on the line PQ , the straight line which is perpendicular to the contour lines at both P and Q . Only the points on this straight line are necessary for the purpose of migration and the rest of the contour lines of both the surface of maximum convexity and of the surface of equal reflection times may be dispensed with.

In the case shown in figure 9, shotpoint and receiver have been chosen to coincide. A surface of equal reflection times then is the same as a wavefront originating at this coincident point of shotpoint and receiver. If the velocity distribution is a function of depth only, such a wavefront is axially symmetrical and the same applies to a surface of maximum convexity.

Such a surface consisting of contour lines which are concentric circles, a two-dimensional representation, is fully determined by the points of intersection with a line through the centre, a one-dimensional representation. Each surface, either a wavefront surface or a surface of maximum convexity, can be represented by such a row of points on a straight line. All these rows of points can then be combined into a pair of two-dimensional templates, one representing all wavefront surfaces and the other all surfaces of maximum convexity.

In this way the use of a prohibitively large number of contour maps of surfaces to fit all possible depths is avoided, so that the method of fitting surfaces at all depths and inclinations becomes feasible. Only two templates must be prepared and these turn out to be the same pair of charts as used for two-dimensional migration in the manner shown in fig. 11.

It must be clearly borne in mind that the representation of an infinite number of surfaces by a template in the manner described can only be carried out for axially symmetrical surfaces. This means that the three-dimensional migra-

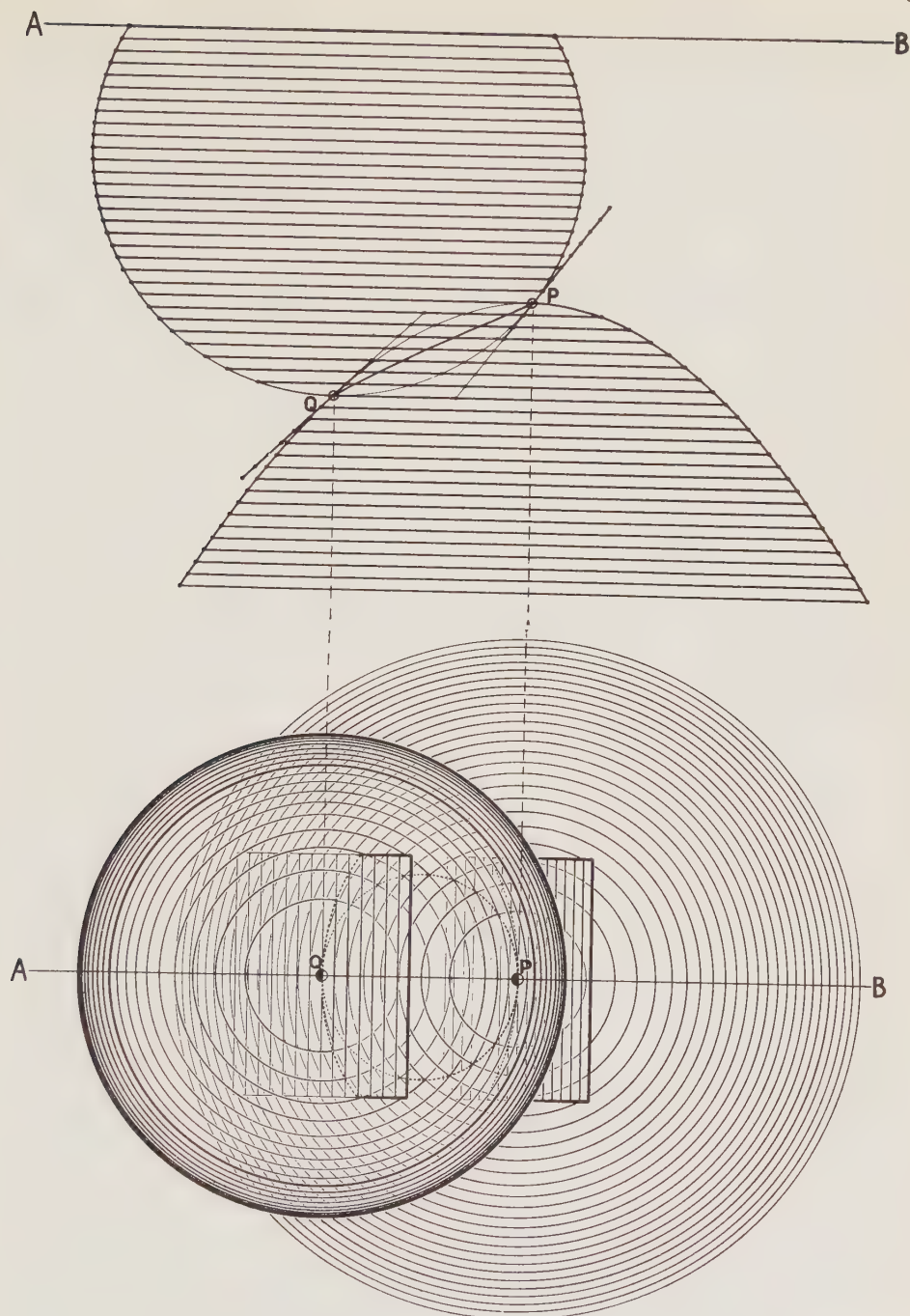


Fig. 13. Representation of the case of fig. 9 by contour lines.

tion method here described can, strictly, only be used in the case of normal incidence, or coincidence of shotpoint and receiver. This point will be further elaborated in paragraph VI, 1.

2. Charts to be used as templates for three-dimensional migration.

By the following line of reasoning it can be seen how these templates can be arrived at.

The simplest derivation of a curve of maximum convexity from the wavefront chart, without using auxiliary construction lines, is shown in fig. 14A, comparable to figure 6, but with shotpoint and receiver coinciding.

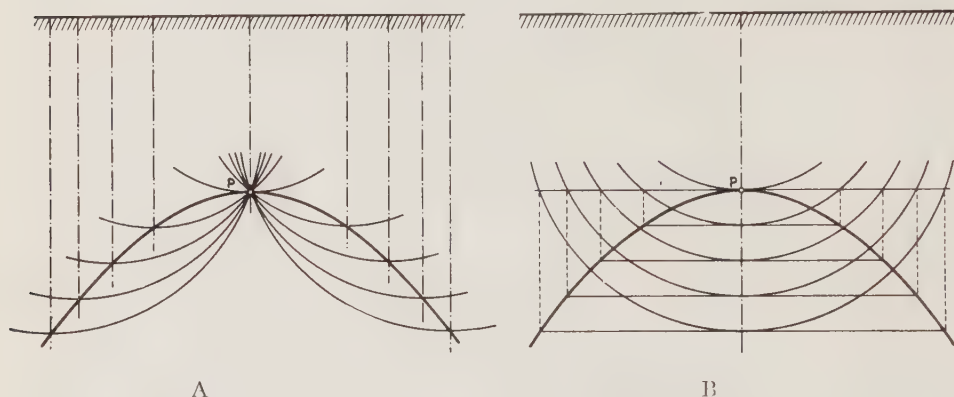


Fig. 14. Two procedures for deriving a curve of maximum convexity from the wavefront chart.

wavefront chart is shifted in a horizontal direction underneath a transparent overlay until a wavefront runs through P. The intersection point of this wavefront with the axis of the chart is then plotted, and that of other wavefronts in similar manner. It can also be carried out as shown in figure 14B, leaving the wavefront chart in the central position. The intersection of a horizontal line through P with a wavefront is projected downwards to the maximum depth of that wavefront. This construction is obviously the same, in principle, as the one shown in fig. 14A.

It is clear that a curve of maximum convexity, obtained in whatever manner, depends only on the depth of its intersection with the axis and, obviously, not on the spacing of the wavefronts on the chart from which it has been derived.

In fig. 15 a wavefront chart has been drawn with the wavefronts spaced at regular maximum depth intervals and the curves of maximum convexity, which cut the axis at the same equally spaced depth values, have been derived from these wavefronts.

At the right hand side of the axis in fig. 15 the same method of constructing

the curve of maximum convexity c is shown as in fig. 14B. Fig. 15 can be regarded as a vertical plane through the axis of a set of wavefront surfaces and surfaces of maximum convexity spaced at equal depth intervals at the axis. The circles of intersection between the horizontal plane h and the wavefront surfaces are then seen to be the contour lines representing the surface of maximum convexity c . In the plane of drawing the intersection points of the line h with the wavefronts then are a linear representation of the contour lines

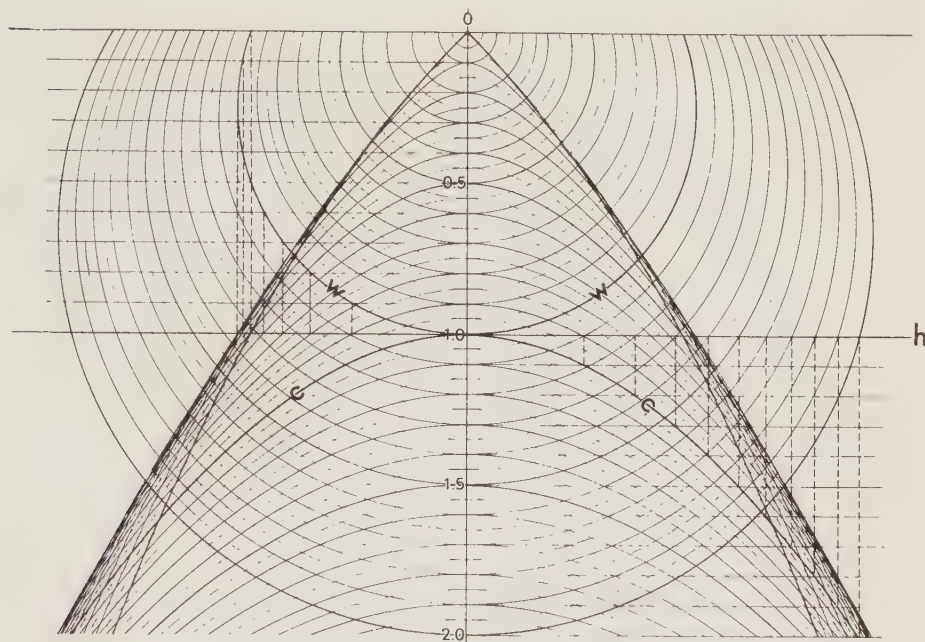


Fig. 15. Mutual projective relationship between wavefronts and curves of maximum convexity.

of the surface of maximum convexity c with its top at the depth of h . This means that the wavefront chart can be used as a template representing all possible surfaces of maximum convexity.

At the left hand side of the axis in figure 15 the intersections of the horizontal line h with the curves of maximum convexity are seen to be the vertical projections of points of the wavefront w at consecutively shallower depths. If figure 15 is again regarded as a plane through the axis of a set of wavefront surfaces and surfaces of maximum convexity, a circle formed by the intersection of the horizontal plane h with a surface of maximum convexity is a contour line on the wavefront surface w . Consequently, the chart of curves of maximum convexity can be used as a template representing all wavefront surfaces.

3. Migration of contour lines with the aid of a pair of charts.

Fig. 16 illustrates a procedure for migrating a vertically plotted surface represented by contour lines spaced at the same depth intervals as the wavefronts and the curves of maximum convexity on the charts used as templates.

A certain point Q , midway between the contour lines 28 and 29, is to be migrated. The chart of curves of maximum convexity is orientated underneath the transparent contour map, keeping its axis parallel to the mean direction

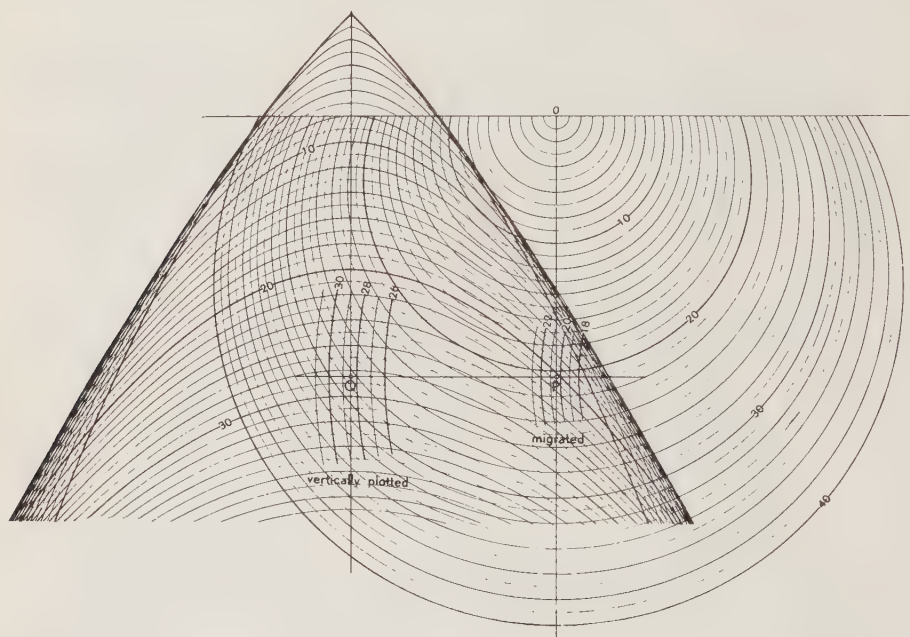


Fig. 16. Migration of contour lines with the aid of a wavefront chart and a chart of curves of maximum convexity employed as templates.

of the contour lines adjacent to Q , to a position where Q lies on the axis and midway between the curves of maximum convexity 28 and 29. The wavefront chart is then orientated, also underneath the contour map, and also keeping its axis parallel to the mean direction of the contour lines adjacent to Q . It is moved to a position where the intersection between the wavefront 28 and the contour line 28 and also the intersection between the wavefront 29 and the contour line 29 both lie on the line through Q which is perpendicular to the mean direction of the contour lines adjacent to Q . The point P where this perpendicular line then intersects the axis of the wavefront chart will be the migrated position of Q . The curves of maximum convexity adjacent to P will intersect the line QP at the same points as the migrated contour lines adjacent to P , which are, of course, also perpendicular to QP .

Thus, the wavefront chart determines the position of P on the map and its

depth, and the chart of curves of maximum convexity determines the dip at P by giving the position of the contour lines adjacent to P.

Because of the finite spacing of the contour lines the assumption has been made, during this construction, that the curvature of the vertically plotted surface at Q in the vertical plane through QP is the same as the curvature of the curve of maximum convexity through Q, which curve is essentially convex. At the same time the assumption has been made that the curvature of the actual reflecting surface at P is the same as that of the wavefront through P, which curve is essentially concave. These assumptions are obviously contradictory and introduce a certain error which, however, can be kept reasonably small by choosing a sufficiently close spacing of the contour lines and, correspondingly, also of the curves on the charts employed.

On enclosure A3 two examples are shown where this method of migration has been carried out with the aid of the enclosed wavefront chart A1 and the corresponding chart of curves of maximum convexity A2. These examples correspond to a velocity V_z linear with depth z : $V_z/V_0 = 1 + z/L$. All distances have been scaled with L as unit and the contour lines on enclosure A3 have been spaced at intervals of $0.01 L$ to correspond with the axial intervals on both charts. The reader can familiarize himself with the method of migration by enlarging enclosures A1, A2 and A3 on separate sheets of transparent material to a conveniently large scale where L is exactly the same, for example 10 cm, on all three sheets.

The examples chosen on enclosure A3 are purely hypothetical cases. The shooting system included the shooting of cross-spreads, each comprising two full spreads across the line. If, in practice, this system yields sufficiently clear reflections, a reliable three-dimensional picture of a vertically plotted horizon is obtained in a band below the line itself, and the migrated horizon may be derived as the corresponding band. In this way a clear picture is obtained of those parts of the reflecting horizon that have been actually determined.

4. *Practical application of the proposed method of migration.*

By referring back to figure 16 it is clear that for migrating contour lines, obtained by vertically plotting reflection points, three separate things are required in a particular disposition in relation to the small portion of the contour map to the migrated. These three separate things are:

- (a) the straight line PQ, along which migration is to take place,
- (b) a chart of curves of maximum convexity, representing wavefront surfaces and
- (c) a wavefront chart, representing surfaces of maximum convexity.

Their particular disposition must always satisfy the condition that the axes of symmetry of (b) and (c) are perpendicular to (a).

One way of achieving any desired disposition of (a), (b) and (c) is to draw

them on separate transparent sheets and determine their relative movements by a device where, one chart (b) taken as position of reference, the sheet with the straight line (a) can move in one direction, a slide, and the other chart (c) can move so that the axes of the two charts remain parallel.

This arrangement is shown diagrammatically in fig. 17. The sheet with the line of migration (dashed lines) can slide up and down with respect to the sheet containing the chart of curves of maximum convexity (dot-dash lines) and the sheet with the wavefront chart (full lines) is connected to the other chart with a simple linkage to keep their axes parallel.

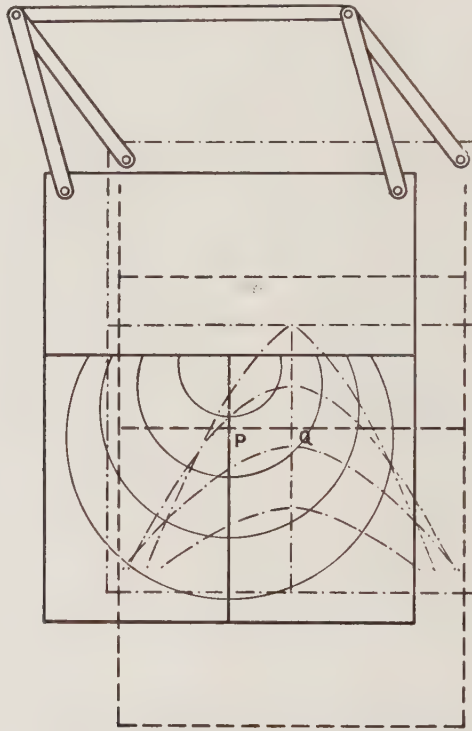


Fig. 17. Relative disposition of the three sheets employed in migrating contour lines.

The manipulation of this system underneath a contour map can be carried out in practice with the aid of a commercial drawing machine, but this means that the contour map cannot remain in a fixed position in regard to the drawing board.

A suitable arrangement is illustrated in figure 18. Two strips of stiff white cardboard are affixed to the drawing board so that a long third strip, the width of the chart of curves of maximum convexity, can slide between them. The line of migration is drawn across this sliding strip. The transparent chart of curves of maximum convexity is attached to the fixed strips with tape after



Fig. 18. Illustration of a practical application of the three-dimensional migration method.

ensuring perpendicularity of its axis to the line on the sliding strip. The wavefront chart must be printed at the lower end of a fairly long strip of transparent film so that when attached, correctly aligned with the chart of curves of maximum convexity, to the drawing machine, its points of attachment will not interfere with the overlying contour map when the chart is moved about beneath it.

With this apparatus the procedure of migration is as follows:

1. The contour map is orientated so that the point to be migrated lies at the correct depth on the axis of the chart of curves of maximum convexity and so that the unmigrated contours at the point are parallel to the axis.
2. The slide is moved to bring the line of migration to pass through the point to be migrated.
3. The wavefront chart is moved to the position in which the corresponding wavefronts and contours, near the point to be migrated, cut one another on the line of migration.
4. The migrated point is located on the axis of the wavefront chart on the line of migration, and short portions of the migrated contours should be drawn close to this point, perpendicular to the line of migration and their depth values marked to satisfy the intersections of adjacent curves of maximum convexity with the line of migration.

IV. WAVEFRONT CHARTS FOR VERTICAL PLOTTING, BASED ON TIME-DEPTH RELATIONSHIPS

1. Centres of curvature of the wavefronts at the vertical axis.

When a wavefront chart is used for the purpose of vertical plotting of

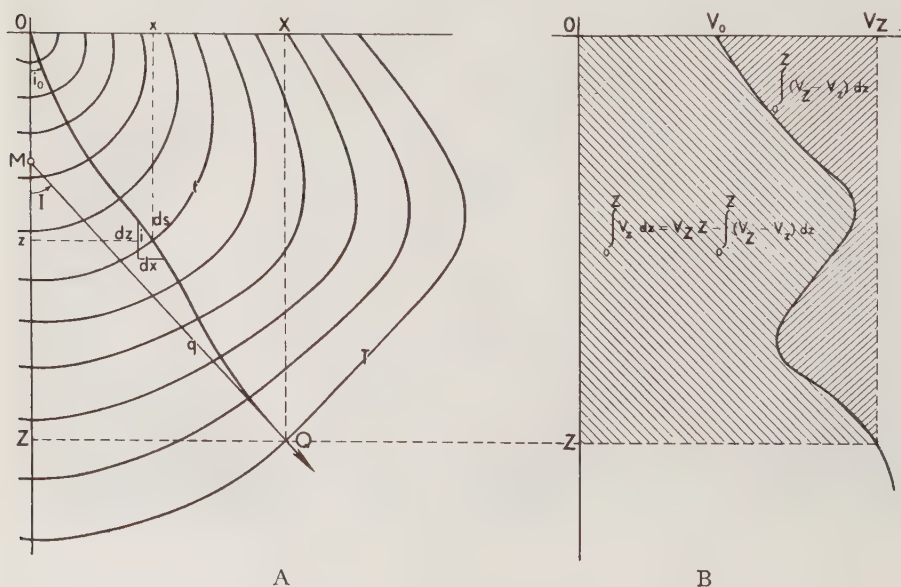


Fig. 19. The curvature of a wavefront is a function of depth and velocity distribution to that depth.

reflection times, in the manner described in paragraph I,1, this chart is only used in a narrow band near the axis, up to a distance from this axis of half the distance between shotpoint and furthest receiver. As a first step in approximating these central parts of the wavefront curves, they can be represented by segments of circles even though the velocity does not increase linearly with depth. The depth to the centre of one of these approximating circles must be some function of the velocity distribution down to the maximum depth of the particular wavefront.

In fig. 19A a number of wavefronts at equally spaced time intervals and also one trajectory originating at O have been drawn, corresponding to the velocity distribution shown in figure 19B. The form of such a trajectory, a line orthogonal to the wavefronts, is fixed by the condition, Snell's law, that $V_Z/\sin i$ remains constant. The distance $MQ = q$ can be found in the following way:

$$\frac{dx}{ds} = \sin i; \quad X = \int_{"O"}^{"Q"} \sin i \, ds$$

$$q = \frac{X}{\sin I} = \int_{"O"}^{"Q"} \frac{\sin i}{\sin I} \, ds = \int_{"O"}^{"Q"} \frac{V_z}{V_Z} \, ds = \frac{1}{V_Z} \int_{"O"}^{"Q"} V_z \, ds$$

The distance q is not necessarily the radius of curvature of the wavefront at Q . The centre of curvature at Q would be the intersection point of two lines perpendicular to the wavefront at points at infinitesimally small distances on both sides of Q , and this intersection point will not necessarily lie on the axis. Because of the symmetry at the point where a wavefront cuts the axis, the centre of curvature of the arc at this point must lie on the axis and then the radius of curvature will be the value of q for $i_0 = 0$ or for $ds = dz$:

$$R_Z = q(i_0 = 0) = \frac{1}{V_Z} \int_0^Z V_z \, dz$$

The depth to the centre of curvature is:

$$Z_c = Z - R_Z = \frac{1}{V_Z} \int_0^Z (V_Z - V_z) \, dz$$

The integrals in these equations for the radius of curvature and for the depth to the centre are illustrated in figure 19B as the shaded areas at both sides of the curve representing V_z as a function of z . These areas must be divided by V_Z , the velocity attained, in order to arrive at the values of R_Z and Z_c . One important fact is directly evident from this representation: the depth to the centre of curvature remains constant for any depth interval where the velocity remains constant.

2. *Elucidation of time-distance graphs by using oblique coordinates.*

A wavefront surface is determined by the travel time and by the velocity distribution. This velocity distribution is usually derived from a vertical time-depth relation obtained directly by carrying out measurement in wells or indirectly from seismic reflection or refraction data.

On a time-distance or t , x graph, whether it is a time-depth graph from a well survey or a refraction time-distance graph, the slope of the curve at a certain point, dx/dt , represents a velocity at a certain depth. A curve built up of straight line segments implies the existence of layers with constant velocities, and a gradually changing slope implies a gradual change of velocity with depth. A clear analysis of these graphs, however, is often difficult because the changes in velocity are often small and the observational errors relatively large.

Distance values can always be measured to an accuracy which makes their uncertainty negligible as compared to that in the measurement of travel times, for which the uncertainty of both the moment of the explosion and the moment of arrival is at least one millisecond in practice. To express this in a graph means that the time scale must be chosen sufficiently large, for example one millisecond equal to one half millimeter, and this leads to very large graphs in practice. These considerations, however, do not apply, in principle, to the choice of the distance scale.

This leads to the two lines of approach illustrated in fig. 20. The original small graph does not show the uncertainties of the time measurements because the scale is too small. As a first line of approach, only the time scale can be enlarged but then a very steep curve is obtained where the uncertainties in the time measurements are not clearly seen because they occur in a vertical direction and not in a direction perpendicular to a mean curve through the points. The only possible way to improve this picture, using rectangular coordinates, is, as shown in fig. 20, by also enlarging the distance scale, even though this is not necessary for the purpose of observing irregularities in the distance values.

A more profitable line of approach is by not only enlarging the time scale but by also inclining the distance axis to where the mean curve, defined by the points, will be approximately vertical to the time axis. The deviations of the points from this curve then refer to uncertainties in the time measurements only. Further advantages are that the graphs can be confined to small areas and that, by using a smaller distance scale, a change in velocity results in a more marked change in slope than on the graphs with rectangular coordinates.

The increased facility in analysing time-distance relations, by using this procedure of plotting on oblique coordinates, must outweigh the difficulty of converting to an unusual operation. Plotting on oblique coordinates can also be conceived, algebraically, by subtracting from each time value an amount proportional to the corresponding distance value and then plotting on rectangular coordinates. This means that the variations of the time values from a straight line, the line $t = x/2500$ in fig. 20, are plotted; this procedure

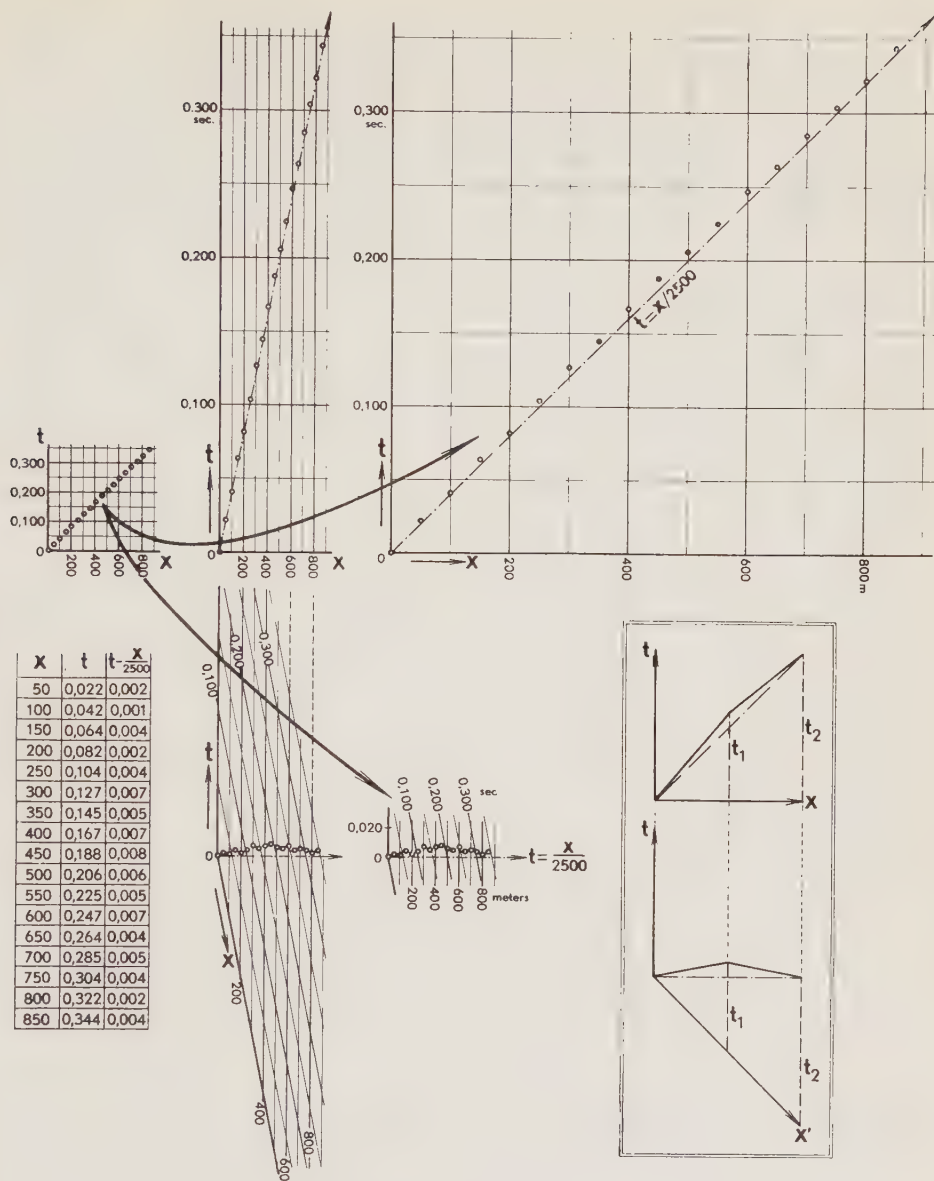


Fig. 20. The analysis of a time-distance curve is facilitated by plotting on a graph with inclined distance axis.

is exactly the same, in principle, as plotting on oblique coordinates but may be found easier to carry out in practice. It is helpful actually to draw a few inclined lines of equal time at unit intervals in order to be able to evaluate at once the velocity corresponding to a certain slope.

3. Derivation of wavefront charts from observed time-depth values.

In fig. 21 a practical example has been worked out. The time-depth values from a well survey have been plotted in fig. 21A on oblique coordinates, where the line $z/t = 2.5$ Km/sec is perpendicular to the time axis.

The interval velocities between successive points were computed and plotted in fig. 21B as the full line. From these the depths Z_c to the centres of cur-

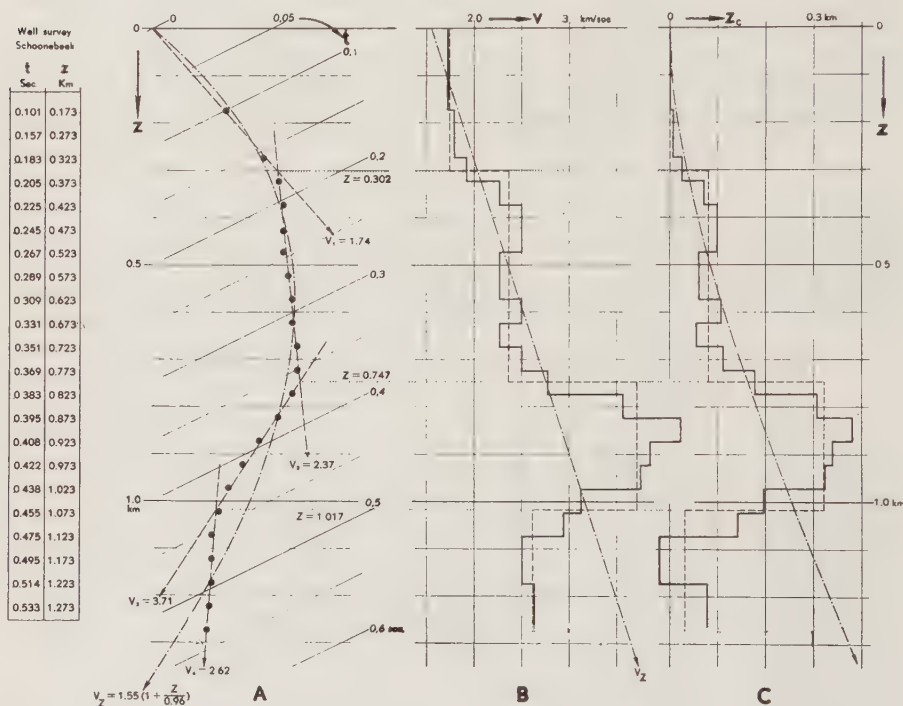


Fig. 21. Different approximations to a velocity distribution and corresponding depths to centres of curvature.

vature were computed for each velocity interval by summation of the values $(V_Z - V_z) \Delta z$, where Δz is the thickness of the layer with velocity V_z :

$$Z_c = \frac{1}{V_Z} \sum (V_Z - V_z) \Delta z, \text{ for all values of } V_z \text{ and } \Delta z \text{ down to } Z.$$

In this manner a step-graph, the full line in fig. 21C, is obtained which is very similar to the graph of interval velocities, the full line in fig. 21B.

Up to this point a mechanical procedure has been followed in which only the actually measured values have been used. This particular case of fig. 21,

however, most probably concerns four layers, each with a constant velocity because the time-depth values in fig. 21A can be approximated to within two milliseconds by four straight line segments, the dashed lines in fig. 21A. The corresponding velocity distribution and depths to the centres of curvature are shown as dashed lines in fig. 21B and 21C respectively.

The time-depth values in fig. 21A can also be approximated by a linear velocity distribution, $V_z = 1.55 (1 + z/0.96)$, the dot-dash line, which approximates the actual time-depth values to within 10 m down to a depth of 0.850 Km and to within 40 m below that depth. This velocity distribution and the depths to the centres of curvature of the corresponding wavefronts are shown as dot-dash lines in fig. 21B and 21C respectively.

In fig. 22 a wavefront chart corresponding to this practical example has been drawn. The full curves are the wavefronts corresponding to the four layers

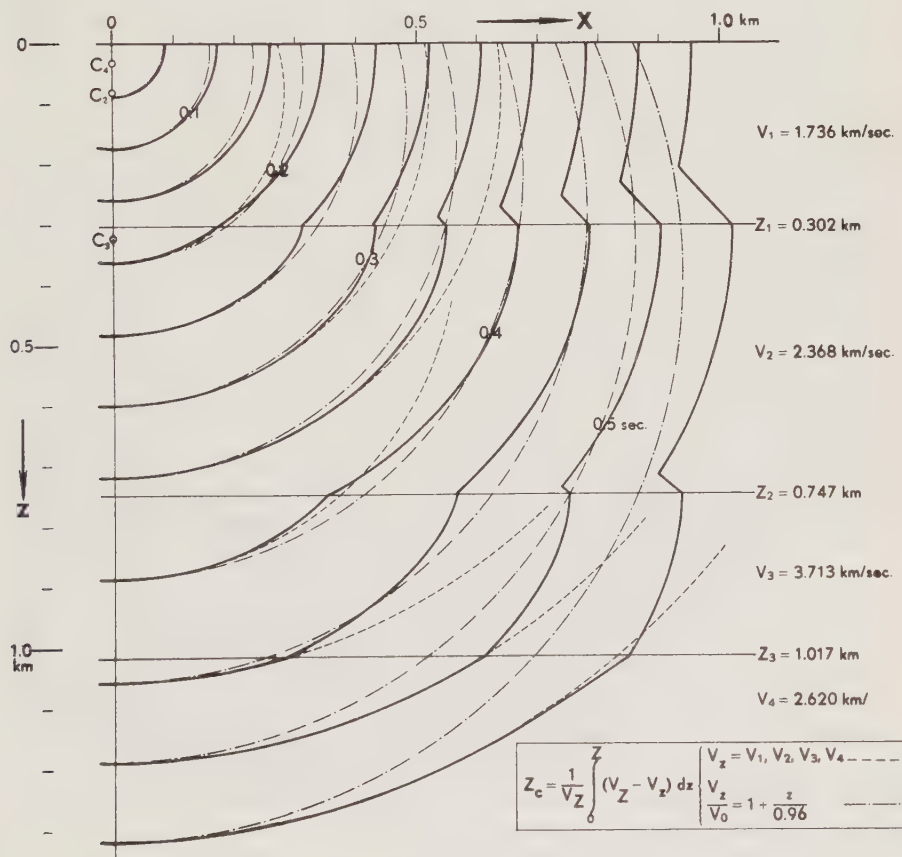


Fig. 22. Wavefronts corresponding to the velocity approximations in fig. 21.

with constant velocity as they most probably actually exist. The centres of curvature of these wavefronts at the axis are O , C_2 , C_3 , C_4 and the circles with these points as centres have been drawn as dashed lines.

It is clear from fig. 22 that in this case these approximate wavefronts can be used for vertical plotting up to shooting distances of at least 400 m without incurring observable errors.

A different line of approach would be by approximating the relation between the depth to the centre of curvature Z_c and the depth Z by a smooth curve as shown in fig. 21C, where the dot-dash line corresponds to a linear relation between depth and velocity. By using these centres of curvature the dot-dash lines in fig. 22 have been obtained. These do not approximate the actual wavefronts near the axis as well as the dashed lines, but they do give a better overall approximation of the full wavefronts.

These considerations can lead to a procedure of splitting the derivation of a wavefront chart for vertical plotting into two parts. First the actual vertical time-depth relation found is used to determine the intersections of the wavefronts with the axis, so that the correct depths will be plotted. A certain amount of smoothing out can be applied to the measured time-depth relationship, because its accuracy can be trusted at the place of measurement whereas, elsewhere in the area in which the wavefront chart is to be used the depths to the velocity layers may be different. The extent to which smoothing out can be applied is conditioned by the variations in depths, the velocity contrasts and also by the size of the area for which one wavefront chart is to be used. And second, the actual wavefronts can then be approximated, for the sake of convenience in draughting, by segments of circles. The centres of curvature of these circles are derived from the velocity distribution approximated by a more or less smooth curve, depending on the shooting distance employed. The smoothing out can usually be carried out to a much greater degree than the smoothing out of the time-depth relation.

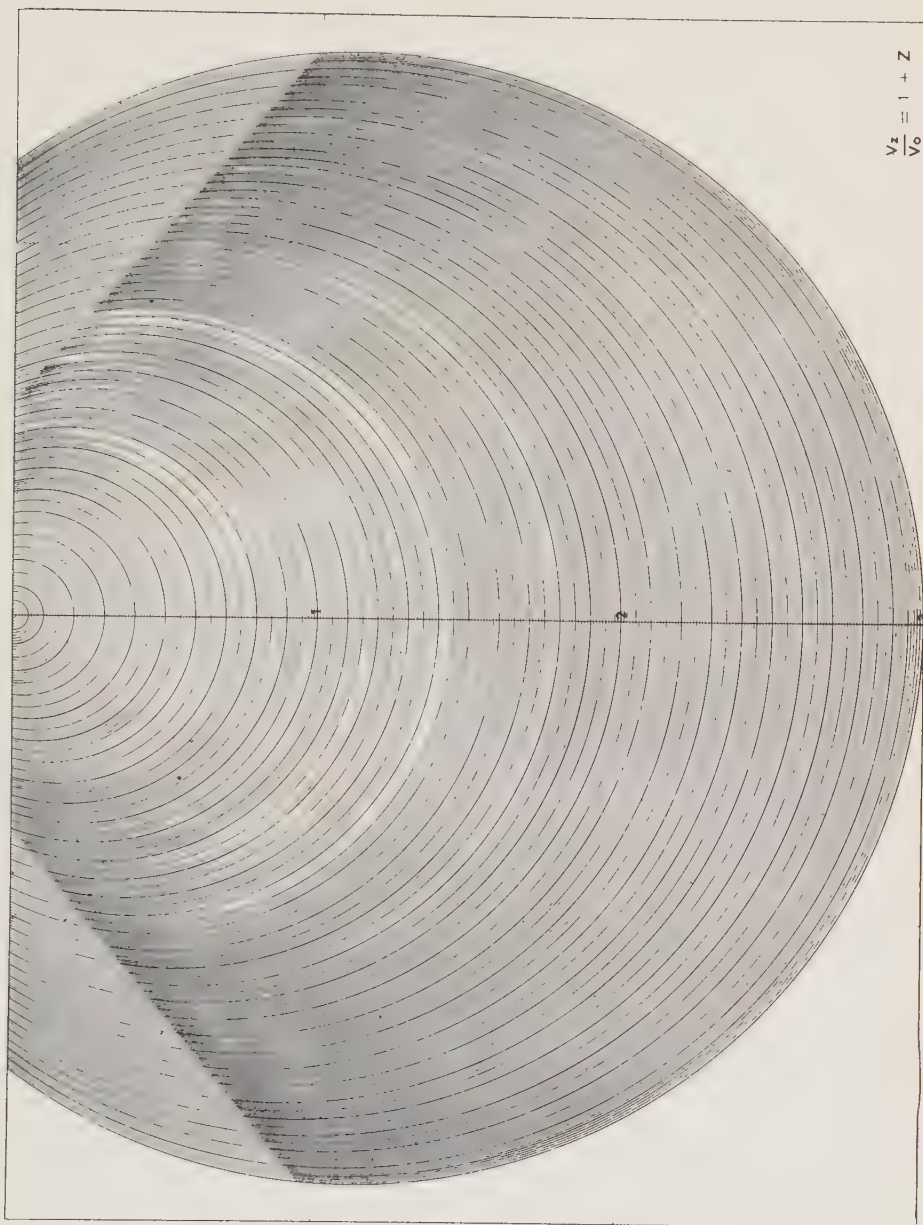
Only in exceptional cases, where it is impossible to approximate the wavefronts by segments of circles will a more complicated procedure have to be followed, but the determination of the curvature at the axis can always be taken as point of departure for constructing non-circular wavefronts.

V. APPROXIMATION OF TIME-DEPTH VALUES BY A SMOOTH VELOCITY FUNCTION

1. *Line of approach when approximating by a smooth velocity function.*

In order to facilitate the construction of a wavefront chart it is advantageous to try to approximate the velocity distribution by a smooth function that lends itself to simple draughting and easy mathematical treatment. In this respect the linear velocity function $V_z/V_0 = 1 + z/L$ is outstanding because it results in circular wavefronts (van Melle).

The approximation must, of course, be within reasonable bounds, depending

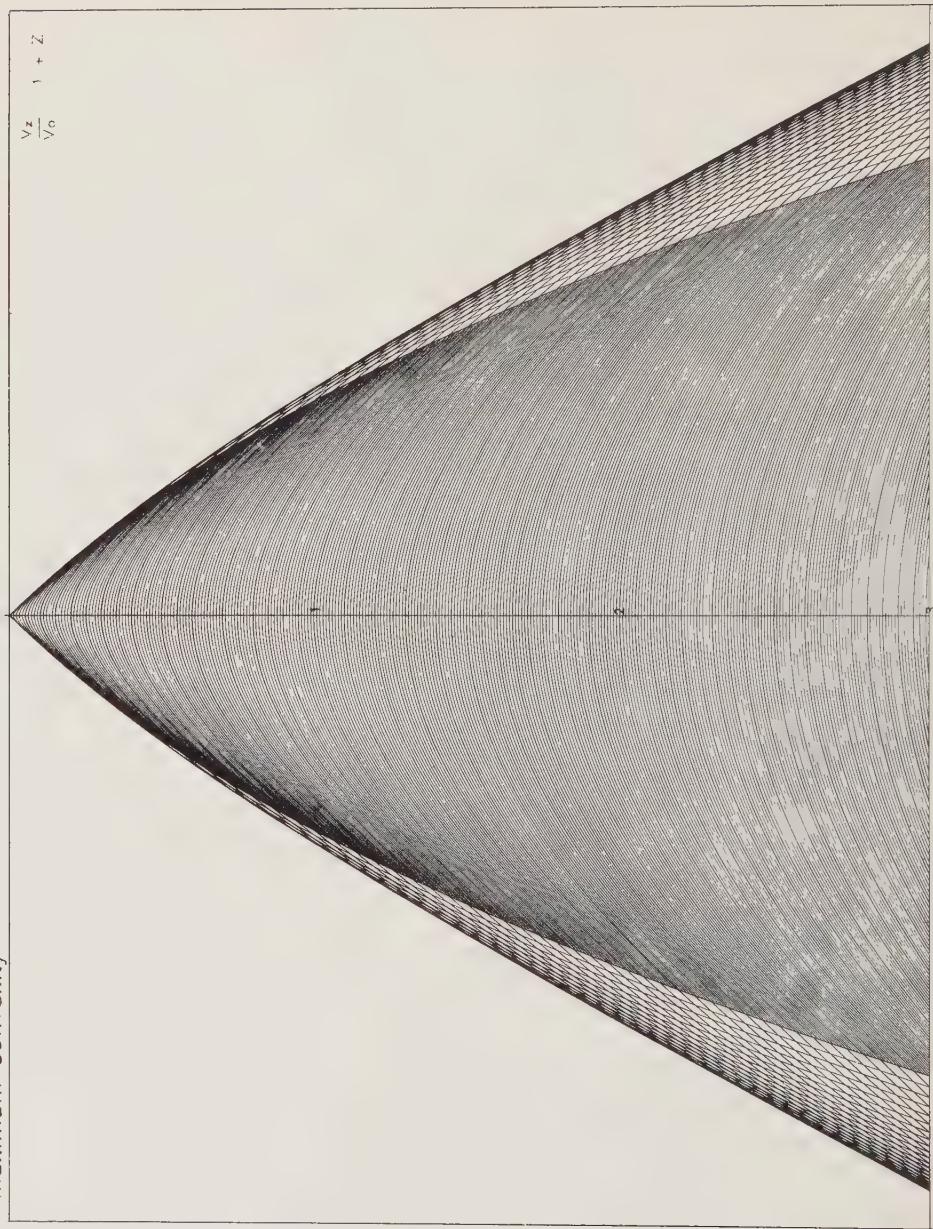


Wavefront chart

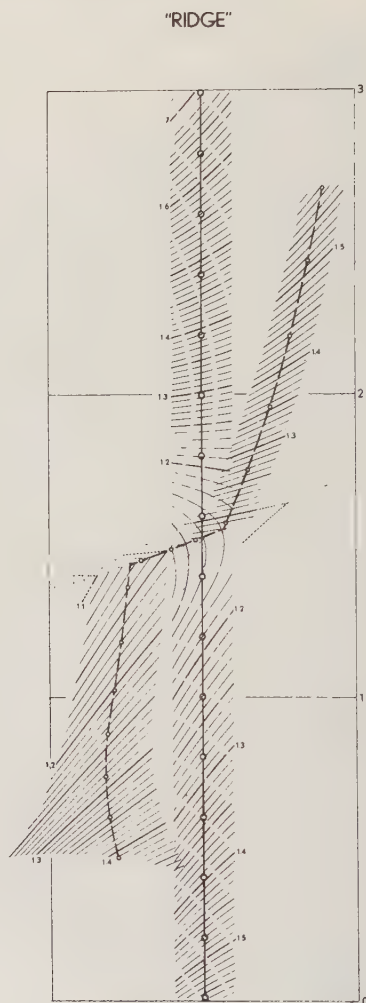
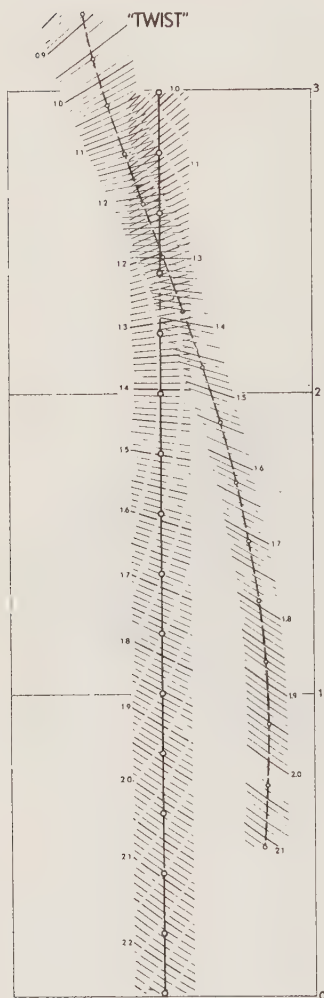
$$\frac{V_z}{V_0} = 1 + Z$$

Enclosure A1

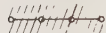
Chart of curves of
maximum convexity



Contour maps migrated with the aid of the charts A₁ and A₂



LEGEND:



LOCATION OF SHOTPOINTS AND LINE OF SEISMOGRAPHS, WITH THE CONTOURLINES OF THE APPARENT REFLECTING SURFACE FOUND BY PLOTTING VERTICALLY.

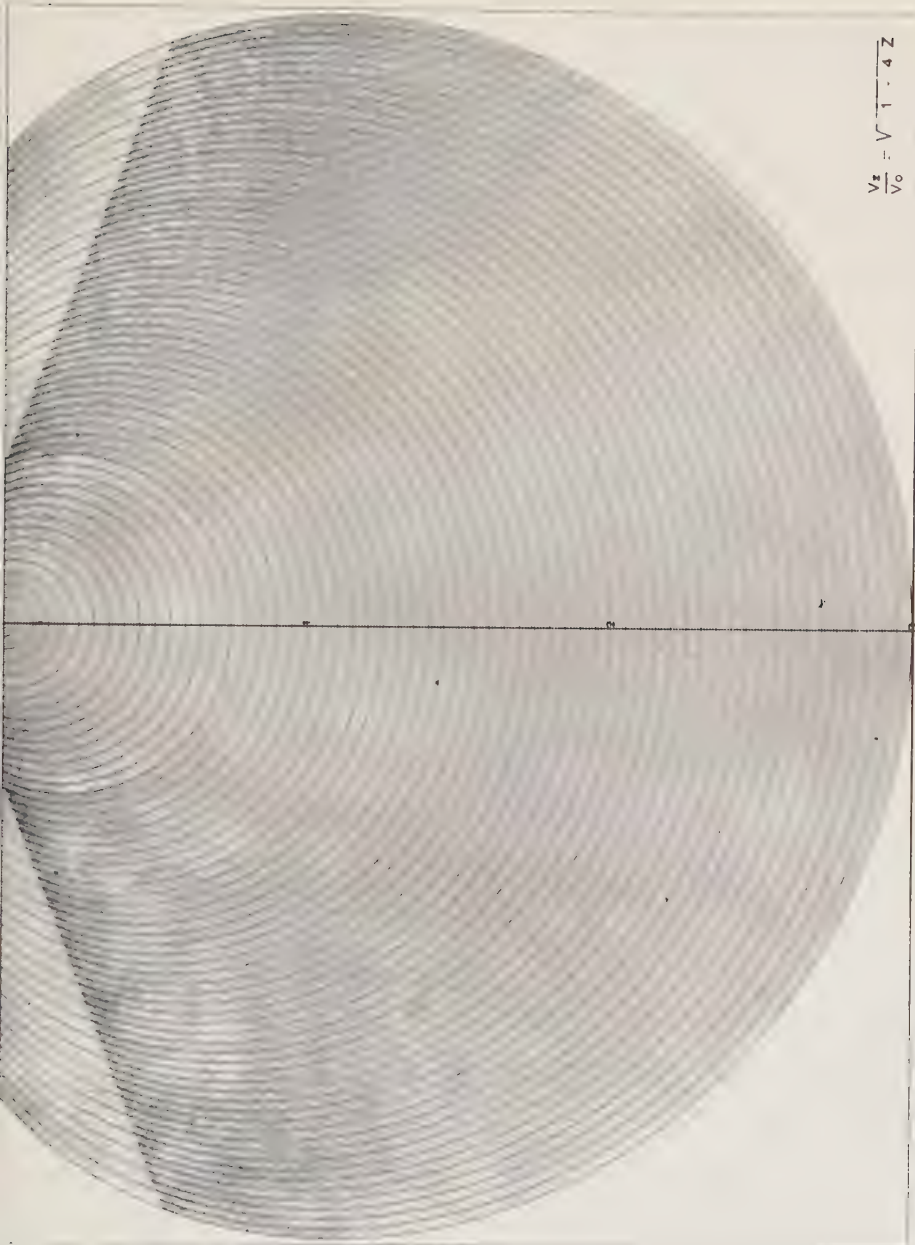


LOCATION OF THE ACTUAL REFLECTING POINTS, CORRESPONDING TO SHOTPOINTS AND LINE, WITH THE CONTOURLINES FOUND BY MIGRATION WITH THE CHARTS.



CONTOURLINES OF THE ACTUAL REFLECTING SURFACE

Enclosure A₃

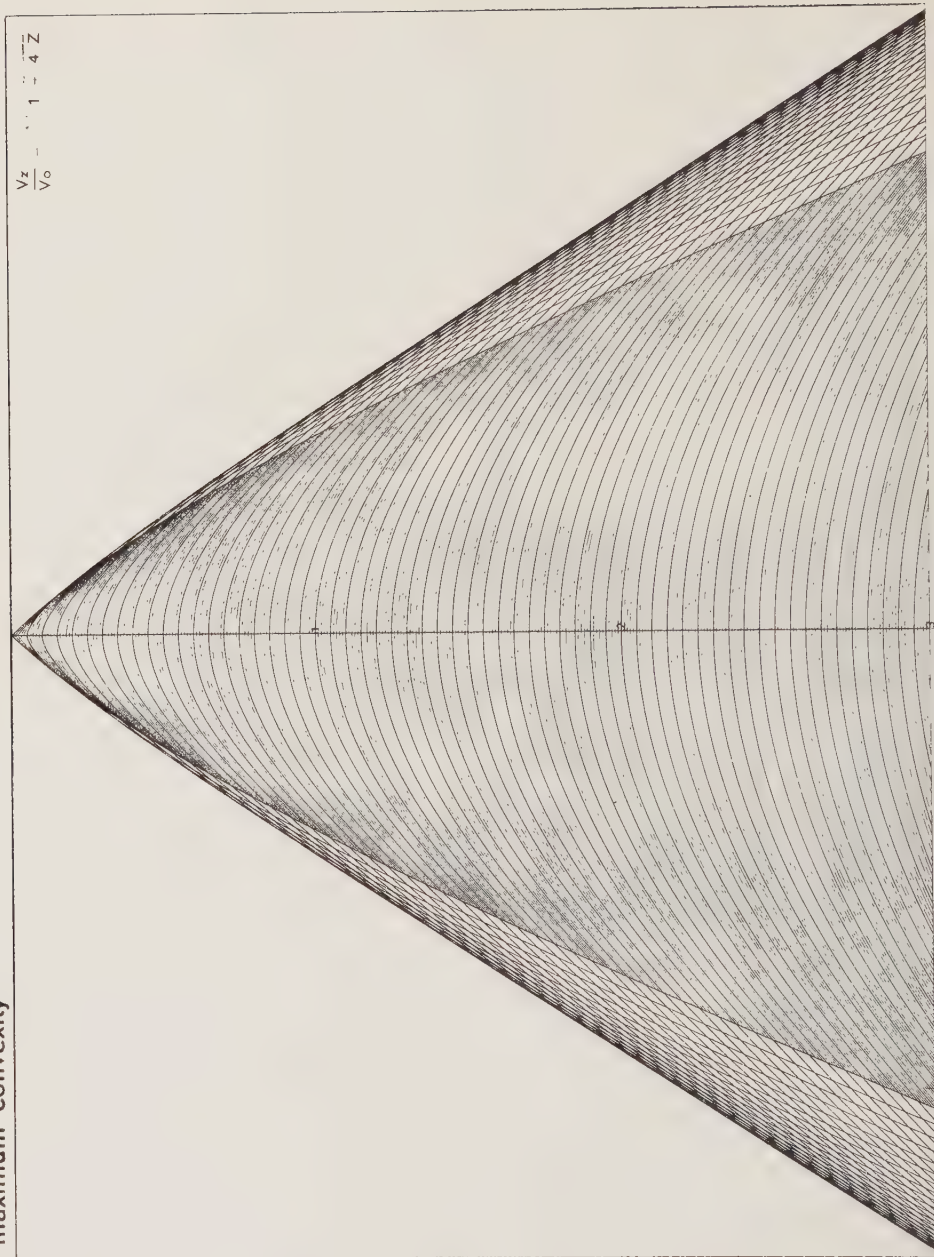


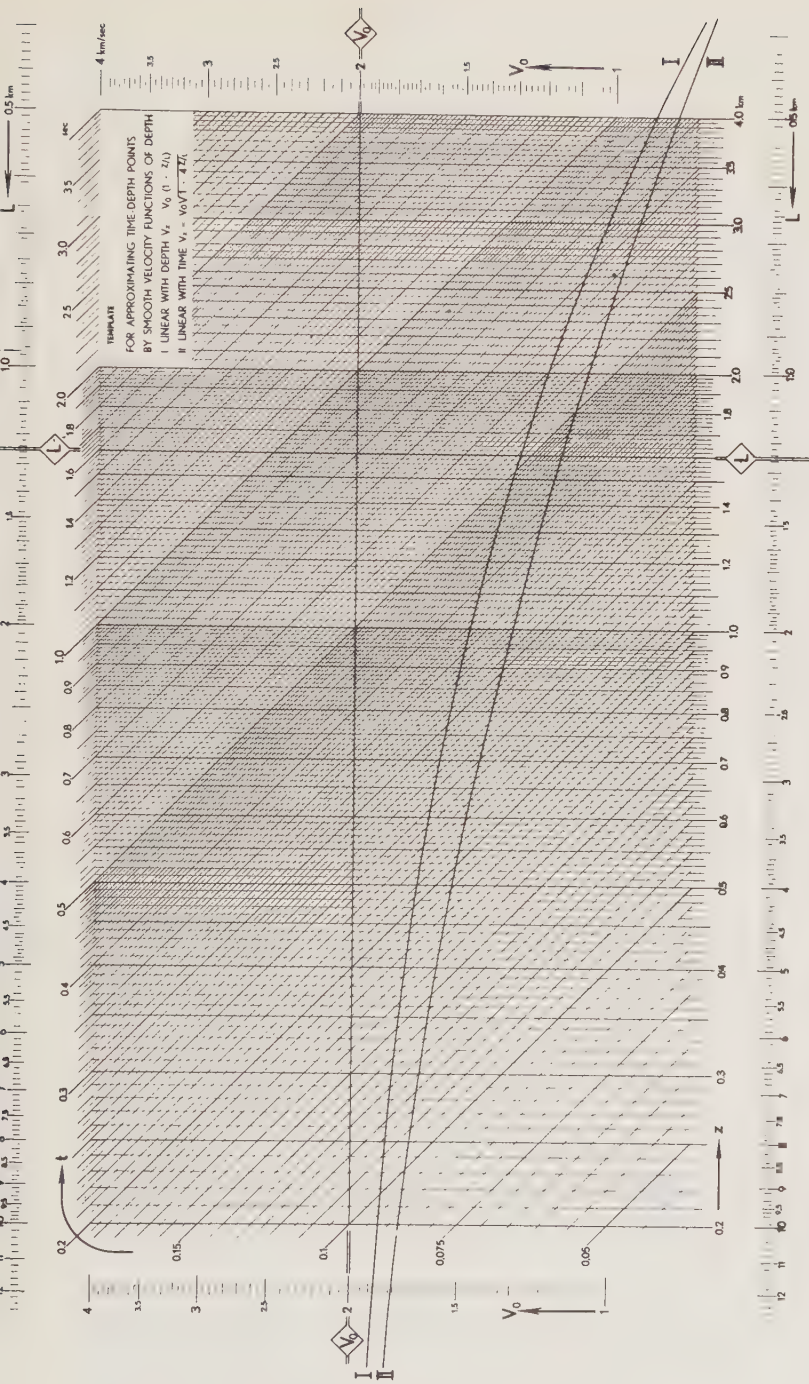
$$\frac{V_z}{V_0} = \sqrt{1 - 4Z}$$

Wavefront chart

Enclosure B1

Chart of curves of
maximum convexity





Enclosure C

on the accuracy required and the observational errors of the available data. It is clear that the aim is not to approximate the velocities as closely as possible but to find a function that will result in depth values that are as close as possible to the actual depths for measured time values.

This point is illustrated in fig. 23 by a simple hypothetical case of three layers of equal thickness and equal increase in velocity from one layer to the next. The velocity distribution, the stepped full line in fig. 23B, can be approximated by a linear increase with depth and the best fit is obviously by

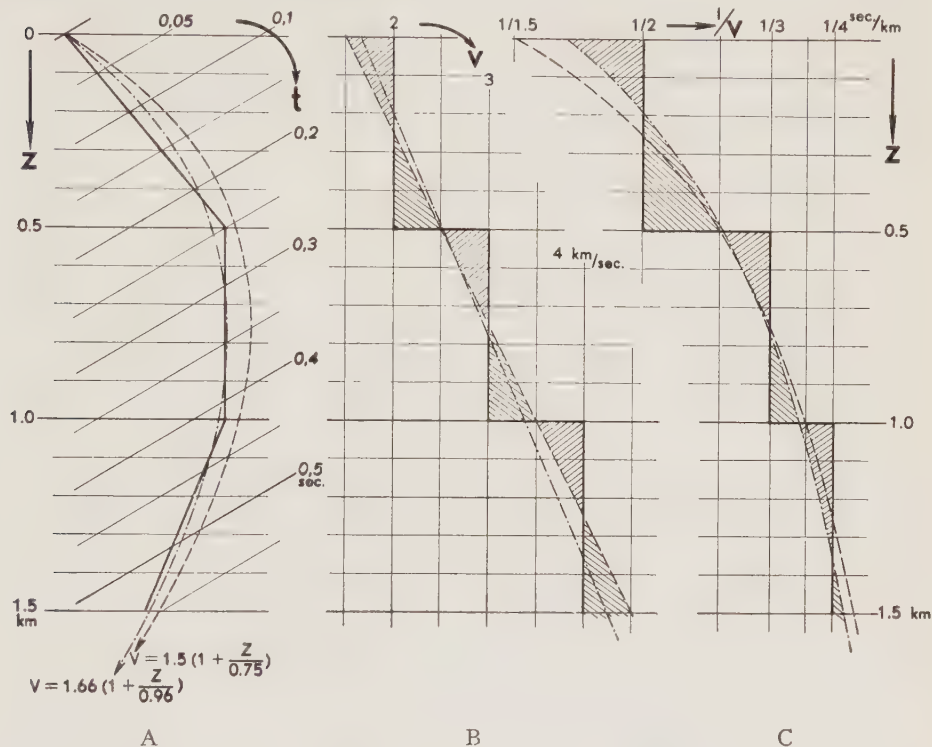


Fig. 23. The best smooth approximation to the velocity distribution is not the best approximation to the time-depth relation.

$V_z = 1.5 (1 + z/0.75)$, the dashed line in fig. 23B. The dashed line in fig. 23A is the time-depth curve corresponding to this linear velocity distribution, and is certainly not the best approximation to the actual time-depth relation given by the full line; a much better approximation is given by the dot-dash line, corresponding to the linear function $V_z = 1.66 (1 + z/0.96)$. In fig. 23B the dot-dash line also corresponds to this function but does not approximate the actual velocity function as well as the dashed line of the function $V_z = 1.5 (1 + z/0.75)$.

This apparent discrepancy is explained by realizing that, in order to arrive

at a smooth velocity function V_z which leads to the best approximation of the time-depth values, the value of $t_Z = \int_0^Z dz/V_z$ should approximate the actual time value for depth Z as closely as possible. This means that it is not correct to approximate V as a function of z by a smooth curve, a straight line for a linear function. The correct procedure is to approximate the inverse value of V as a function of z by a smooth curve which is not a straight line for a linear velocity distribution. This is shown in fig. 23C in which it is seen that the best approximation is arrived at by a smooth curve for which the sum of the shaded areas on one side of the curve down to any point is equalled as closely as possible by that on the other side. Arriving at serviceable smooth velocity functions in this manner is correct in principle but would be rather laborious in practice.

2. Derivation of a serviceable smooth velocity function.

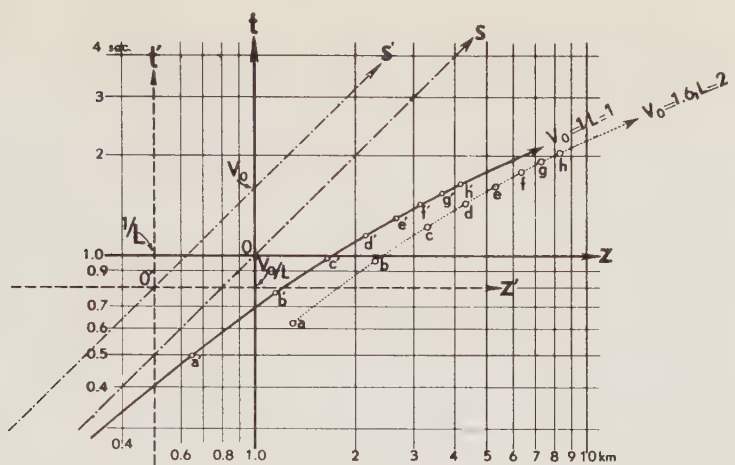
The most direct way to arrive at a serviceable, smooth velocity function is by trial and error using the actual time-depth values available. The first step in this procedure is to try to approximate the time-depth values by a linear function $V_z/V_0 = 1 + z/L$ by varying V_0 and L . If a close enough approximation cannot be arrived at a different function can be tried, for example the parabolic velocity distribution $V_z/V_0 = \sqrt{1 + z/L}$, the velocity function that is linear with vertical traveltime and is also widely used in practice (Musgrave).

The procedure can be shortened appreciably by using a method based on the same principles as a procedure for deriving a smooth velocity function to fit a refraction time-distance curve, introduced by G. Mc G. Bruckshaw at Imperial College, London.

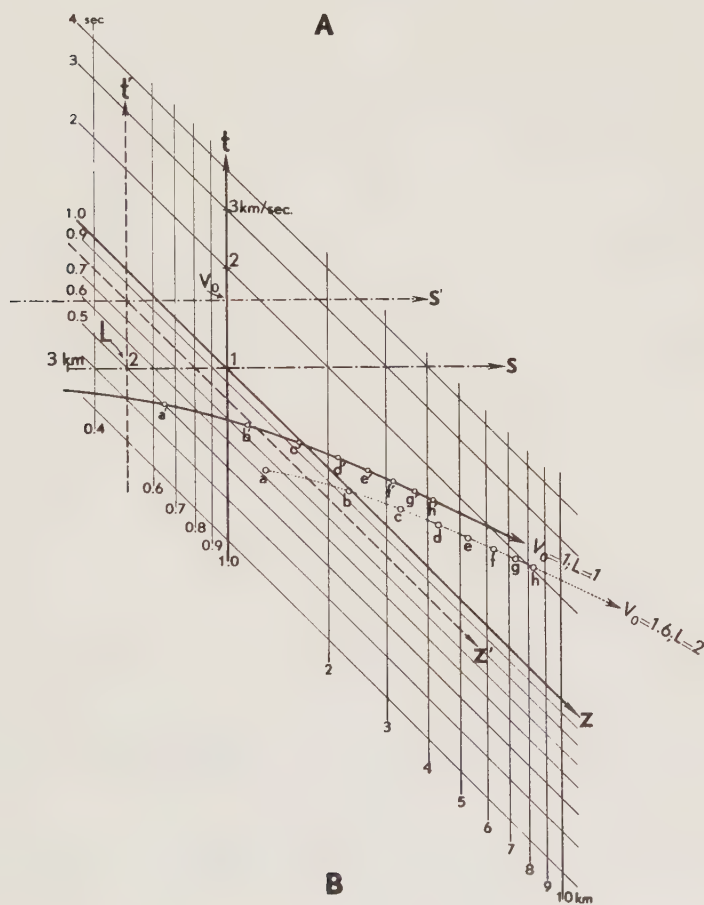
Velocity distributions linear with depth or vertical time can be considered as two families of all velocity functions $V_z/V_0 = f(z/L)$. If F is the reverse function corresponding to f , the time-depth relation can be written as:

$$\begin{aligned} Z &= L F(V_z/V_0) \\ t &= \int_0^Z \frac{dz}{V_z} = \int_1^{V_z/V_0} \frac{1}{V_z} \frac{dz}{d(V_z/V_0)} d(V_z/V_0) = \\ &= \frac{L}{V_0} \int_1 \frac{dF(V_z/V_0)}{d(V_z/V_0)} \frac{d(V_z/V_0)}{V_z/V_0} = \frac{L}{V_0} G(V_z/V_0) \end{aligned}$$

This is a parametric representation of the relationship between t and Z , the parameter being V_z/V_0 . The functions F and G represent the time depth relationship for unit values of V_0 and L . If a time-depth curve, corresponding to arbitrary values of V_0 and L , is plotted on a graph with logarithmic time- and depth-scales, this curve has exactly the same shape as the curve for unit



A



B

Fig. 24. Time-depth curves plotted on logarithmic graphs.

values of V_0 and L . It is only shifted $\log L/V_0$ in the direction of the time-scale and $\log L$ in the direction of the depth-scale.

In order to find a smooth velocity function to fit a set of observed time-depth values, these values can be plotted on a transparent sheet overlying a logarithmic graph containing a number of time depth curves corresponding to different families of functions with unit values of V_0 and L . The transparent overlay can then be moved, keeping the axes parallel, and the best fit found by trial and error.

The procedure is illustrated in figure 24A, making use of a linear velocity distribution $V_z = V_0 (1 + z/L)$. The indicated axes t and z are the lines of unit distance and unit time respectively. The time-depth values a, b, c , etc. are plotted on an overlay and the axes t and z are traced on this overlay. By shifting the overlay in such a way that the plotted time-distance values fall at a', b', c' , etc. on the mastercurve, the traced axes t and z are moved to t' and z' . The line t' will lie on the depth scale at $1/L$ Km and the line z' will lie on the time scale at V_0/L seconds.

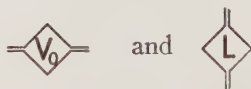
The straight line s represents the time-depth curve for constant velocity $t = z$. This line is moved to s' and it can be seen that it cuts the axis t at the value V_0 , moving from t' to t corresponds to multiplying by L , and s is at equal angles to t and z . Thus V_0 can be read directly on the axis t by tracing the line s on the overlay, omitting the tracing of the axis z .

The importance of this line s and the fact that the curves will lie within fairly narrow bands parallel to this line, leads to the conclusion that it is more logical to incline the z -axis until the line s is perpendicular to t . This transformation has been carried out in figure 24B.

3. *A template for direct determination of a smooth velocity function.*

In order to confine a template to a minimum area, the following considerations have been followed. In the first place the area of the template is fundamentally only limited by the range of t - and z -values to be expected in practice. In the second place the master curves can be drawn for any values of V_0 and L if the axes to be traced on the overlay are drawn through the corresponding values on the V_0 and L scales respectively. Furthermore, these reference axes can be moved together with their respective scales to any more favourable position.

These considerations have been embodied in the template on enclosure C, which can be used directly for most practical cases where the time depth relationship can be approximated either by a function linear with depth, $V_z/V_0 = 1 + z/L$, or linear with vertical travel time, $V_z/V_0 = \sqrt{1 + 4z/L}$. The template must be overlaid by a sheet of transparent drawing paper on which the time depth values are plotted and the axes marked



are traced. The overlay is then shifted to the best fit to one of the master curves and the values of V_0 and L read off at the intersections of the traced lines with the V_0 - and L -scales.

Only two master curves, corresponding to velocity distributions linear with depth and linear with vertical travel time are presented on this template. Other curves, corresponding to other functions $V_z/V_0 = f(cz/L)$, can be included by computing the time-depth relation for $L = 1.25$ and $V_0 = 2$. Choice of c depends on which range of the master curve is desired on the template.

The template on enclosure C is presented on a scale that is sufficiently large but enlargements can, of course, be made if required to facilitate plotting. The lines of equal time have been drawn five milliseconds apart up to the half second line, ten milliseconds apart up to one second and twenty milliseconds apart up to two seconds, so that the time-depth points can be plotted to an accuracy of one to two milliseconds, which is sufficiently accurate in most cases in practice.

It is always possible to plot unusual values within the area of this template by multiplying one or both the coordinate values by a certain factor. A change of the depth values by a certain factor will result in the same change in the values found for both V_0 and L , while a change in the time values will result in only the value of V_0 being different from the value read on the scale of the template.

The main difficulty when plotting on any logarithmic scale is that a certain numerical interval corresponds to different intervals at different locations. A certain error in depth or time corresponds to a diminishing interval along a time-depth curve. The most straightforward solution to this difficulty is by plotting not points but line segments; for example along a line of constant time for a depth interval of ± 20 meters. In this way the measured points can easily be fitted to a curve to within a certain error in depth.

VI. DERIVATION OF THE CHARTS TO BE USED FOR THE PURPOSE OF MIGRATION

1. *Use of wavefronts instead of curves of equal reflection times.*

Up to paragraph III, 2 the concept surface of equal reflection times was used but at that point the necessity arose to use only symmetrical rotational surfaces in order to be able to evolve the two-dimensional templates for the purpose of three-dimensional migration. This will seem, on first sight, to impose a serious limitation on the proposed method for migrating contour lines.

The complications introduced by the asymmetry of the surfaces of equal reflection times at large shooting distances will, necessarily, make any strict method of three-dimensional migration cumbersome in such cases. Fundamentally, any method must be based on the determination of surfaces of equal reflection times, the intersections of which with the plane in the direction

of maximum dip have a different shape for each different angle between this plane and the line shot.

In fig. 25 two wavefront charts have been centred at a shotpoint S and at a receiver R respectively, as was done in fig. 4. Three curves of equal reflection times have been drawn as full lines. The dashed curves are wavefronts that would be obtained from a shot at M and which cut the central axis through M at the same depths as the three curves of equal reflection times. These wavefronts are seen to approximate the curves of equal reflection times fairly well at depths greater than the distance between shotpoint and receiver.

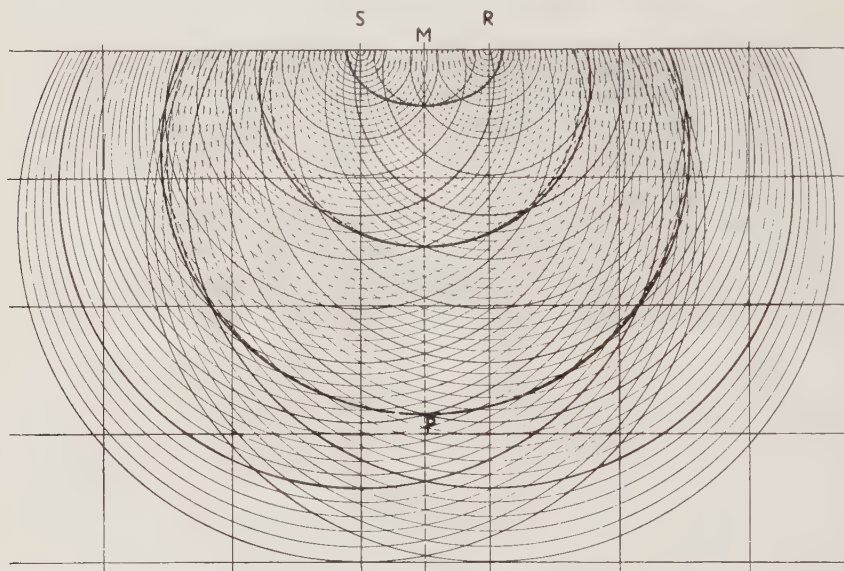


Fig. 25. Approximation of curves of equal reflection times by wavefronts.

When the widely used method of "straddle-shooting", where the shotpoint is located in the middle of a spread of geophones in the order of $\frac{1}{2}$ Km long, is employed, the approximation of curves of equal reflection times by wavefronts is practically always permitted.

In some cases, however, better results are obtained by shooting to larger distances: for example, when a surface wave is too strong or when using a system of air shooting (Poulter).

The longer the distance between shotpoint and receiver, the more elongated a surface of equal reflection time becomes and the less well can it be approximated by a symmetrical wavefront surface. The closeness of this approximation is, however, not a function of depth only but also of the dip of the reflector. For larger dips the approximation is worse but, in practice, the fundamental assumptions on which the use of wavefront charts is based

also become less reliable. In most cases of strongly dipping layers an appreciable change in velocity can be expected in a lateral direction and the velocity distribution cannot be evaluated accurately. Even when using fairly large shooting distances, the errors introduced by approximating curves of equal reflection times by wavefronts can, in most cases in practice, be expected to be of a smaller order of magnitude than the errors introduced by the approximation of the velocity distribution.

For large shooting distances the most straightforward procedure would be to construct a number of curves of equal reflection times corresponding to the approximated velocity distribution and the average shooting distance, both in the vertical plane through S and R in figure 25 and in the vertical plane through M which is perpendicular to the line SR. The best average fit to both sets of curves could then be sought by trying various enlargements of available wavefront charts. This is one of the purposes for which the two enclosed wavefront charts A1 and B1 may be used.

The charts which are used in this way are no longer, strictly speaking, employed as wavefront charts but only as charts of curves that can be made to fit the shape of curves of equal reflection times more or less closely. The wavefronts, shown as interrupted lines in figure 25, which originate at M and approximate curves of equal reflection times spaced at equal time intervals, are themselves not spaced at equal time intervals because, in figure 25, the difference between the traveltime from S to P to R and from M to P and back changes with the depth of P.

It is clear that this spacing of the curves is quite immaterial when used for the purpose of migration. For the purpose of three-dimensional migration the curves must be spaced along the axis to correspond with the contour lines of the reflecting surface, which means a spacing at regular depth intervals instead of a spacing at regular time intervals.

2. Charts based on velocities linear with depth or with vertical time.

Reference has already been made to smooth velocity functions in which the velocity is linear either with depth or with vertical time, and it has been explained that their fairly general popularity is due to relatively simple properties that lend themselves readily to graphical as well as analytical mathematical treatment.

The stress here is that the choice of velocity distributions of these types does not imply that the actual velocity distributions are equally smooth functions, but rather that the convenience implicit in the use of them is not offset by prohibitive errors. Because the velocity distribution linear with depth leads to circular wavefronts and circular trajectories, it is the most convenient in use. When, however, the increase of velocity with depth decreases with depth a parabolic velocity distribution, namely, one that is linear with vertical time, may have to be used and draughting of the wavefronts becomes tedious unless a suitable draughting machine (Musgrave) is available.

The discussion in paragraph II, 2 might seem to imply that for every new velocity distribution a fresh set of wavefronts has to be drawn. This procedure actually claims many adherents, with the frequent result that a chart is used beyond the range within which it agrees sufficiently with the actual velocity distribution, and sometimes where assumption of a smooth velocity function is not permissible. It is important, therefore, to consider means of making suitable charts readily available.

By first plotting vertically with the aid of a wavefront chart and subsequently migrating with another wavefront chart a simpler procedure is achieved in that, for vertical plotting, the wavefront chart is used near the axis where wavefronts can be safely approximated by arcs of circles. But migration requires a full wavefront chart and the corresponding chart of curves of maximum convexity and it may seem, therefore, that no advantage is gained. There is, however, a method of obtaining all wavefront charts and charts of curves of maximum convexity from a small number of such charts for the majority of cases likely to arise in practice. It is simply that of enlarging or reducing the relevant master charts to the required scale.

In the case of a velocity distribution $V_z/V_o = f(z/L)$ in which two wavefronts are considered at times differing by Δt , these wavefronts are separated by a distance $V_z \Delta t$ at a depth z and by $V_o \Delta t$ at the surface. Magnify this picture m times and the separation at depth mz will be $mV_z \Delta t$ and at the surface $mV_o \Delta t$. Clearly, the wavefronts remain possible wavefronts after magnification since their distance apart for a given time interval is a function of depth only. The time interval will become $\Delta t' = mV_o \Delta t / V_o'$, where V_o' is the surface velocity belonging to the case represented by the magnified picture. At the depth mz the velocity will be:

$$V'mz = mV_z \Delta t / \Delta t' = V_o' V_z / V_o = V_o' f(z/L).$$

$$\text{If } z' = mz \text{ and } L' = mL, \text{ then } V'z/V_o' = f(z'/L').$$

The magnified case then concerns a velocity distribution similar to the original function, only with a different value of L . If the wavefronts of the original chart were spaced at equal time intervals at integral values, those of the magnified chart will be spaced at equal time values but no longer necessarily at integral values. The time values will only remain unchanged if $V_o'/L' = V_o/L$. Thus, derivation of other wavefront charts by changing the scale of a given chart has, for plotting purposes, a limited application. But, for purposes of migration, the advantages of this method are irrefutable. For the purpose of migrating contour lines the wavefronts and the curves of maximum convexity must be spaced at equal depth intervals along the axes of the charts and this requirement remains unchanged whatever the magnification. It is only necessary, then, to ensure that the contours to be migrated are spaced at the same interval as the axial interval on the appropriate charts. Although it may be objected that this means a departure from conventional contour spacing and that interpolation is necessary after migration to restore the usual contour spacing, the overall advantages of the method should be apparent.

While several accurately drawn fundamental charts may be necessary to cover all likely practical cases, scale changing of the two enclosed pairs of charts A_{1,2} and B_{1,2} will satisfy the majority of cases to which approximations of the velocity distributions by functions linear with depth, $V_z/V_0 = 1 + z/L$, or linear with vertical time, $V_z/V_0 = \sqrt{1 + 4z/L}$, can be applied. The value of L on the four charts is 4 cm and the axial spacing is 0.1 L . Only in exceptional cases in which L is very large, may the contour spacing not be sufficiently close to warrant the use of these charts.

The two functions $1 + z/L$ and $\sqrt{1 + 4z/L}$ have been chosen to cover a comparable velocity range for comparable values of L . The depth range to $3L$, where the velocity becomes about four times the surface velocity, should be quite sufficient for practically all cases.

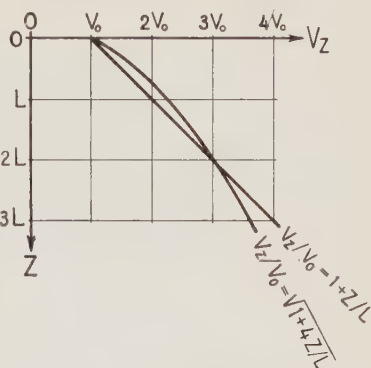


Fig. 26. Velocity functions with comparable range of velocities.

CONCLUSION

Seismic exploration for oilbearing structures is usually carried out under circumstances where speed is as important as the results to be obtained. This is not conducive to experimental work or innovations and brings in the danger of the appearance of a gap between theorists and practicers as is so often observed in immature technical branches of physical science.

An attempt has been made, in this thesis, to avoid this pitfall by stressing the application in practice of the presented processes. Even then their use in actual practice will necessitate the acquirement of unfamiliar techniques. The drawing of a smooth line through a row of more or less scattered points is already a fairly subjective procedure, but drawing aids are available in the form of ship curves. The attainment of this same smoothness, however, in the spacing of contour lines, necessary for the purpose of three-dimensional migration, is already a much more unfamiliar technique for most seismologists.

The introduction of any new method or technique must always be justified by a marked improvement of the results obtained. A difficulty in seismic work is that it is often impossible to check the results. The value of recognizing curves of maximum convexity in order to locate faults has been clearly demonstrated in actual cases, but this alone does not warrant their introduction into an interpretational method. Their importance in this respect is due to the ease in migrating two-dimensionally with their aid, and due to their being essentially required in order to be able to migrate contour lines, whereby a simple method of three-dimensional migration becomes feasible.

Naturally it is important to be able to interpret seismic reflection data in space and not to be compelled to work only two-dimensionally because otherwise the procedures become too involved and cumbersome. The method presented in this thesis is simple enough to warrant a three-dimensional line of thought even in fast routine work. The gain in reliability, by adopting a shooting system including more cross lines or cross-spreads, will, in most cases, outweigh a possible decrease in the rate of progress. The difficulty of introducing an unfamiliar procedure into the interpretation, involving as it does a period of practice before it can compete with customary methods, is only temporary and, thus, cannot be a strong argument against acceptance.

The line of thought followed in this thesis is necessarily incomplete and must be considered as a brief outline upon which an interpretation of seismic reflection data can be based. The circumstances encountered in practice will condition the manner of application and the necessary modifications.

In some regions the assumption that the velocity distribution does not change very rapidly in a lateral direction cannot be maintained. Where a strong jump in velocity occurs at a certain lithological boundary, as, for example, to limestone, it will be necessary first to make an interpretation down to that boundary before attempting an interpretation of deeper layers. This involves, unavoidably, more cumbersome and time consuming techniques.

The advantage of plotting reflection data in two stages, first the vertical plotting and then the migration, is best appreciated in those borderline cases where plotting with the aid of a single chart for the whole depth interval is not permissible but where migration can be done with a single pair of charts, because only the approximate shapes of the curves and not their time values are of consequence. In these relatively numerous borderline cases only the procedure of vertical plotting is complicated but, for the purpose of migration, use can still be made of easily obtainable charts. Thus the process described in this thesis introduces a number of simplifications to offset the apparent complications involved by the stress which is laid on three-dimensional interpretation.

It is, of course, clear that any interpretational work can only be fruitful when reasonably clear experimental data are obtained. The limitation of the results that can be obtained is, primarily, determined by the physical circumstances encountered and by the field procedure and the recording instruments, for the particular method of interpretation employed is of secondary importance.

ACKNOWLEDGEMENTS

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REFERENCES

- BAULE, H.: Laufzeitmessungen an Bohrkernen und Gesteinproben mit elektronischen Mitteln, *Geophysical Prospecting*, I, 2, June 1953.
- CLEWELL, D. H. & R. F. SIMON: Seismic Wave Propagation, *Geophysics*, XV, 1, January 1950.
- DALY, J. W.: An Instrument for Plotting Reflection Data on the Assumption of Linear Increase of Velocity, *Geophysics*, XIII, 2, April 1948.
- DIX, C. H. 1: On the Minimum Oscillatory Character of Seismic Pulses, *Geophysics*, XIV, 1, January 1949.
- 2: Pulse Propagation in Two Spacial Dimensions, *Geophysics*, XV, 3, July 1950.
- 3: *Seismic Prospecting for Oil*, Harper & Bros., New York, 1952.
- HAGEDOORN, J. G.: A Practical Example of an Anisotropic Velocity Layer, *Geophysical Prospecting*, II, 1, March 1954.
- KREY, TH.: The Significance of Diffraction in the Investigation of Faults, *Geophysics*, XVII, 4, October 1952.
- MELLE, F. A. VAN: Wave-front Circles for a Linear Increase of Velocity with Depth, *Geophysics*, XIII, 2, April 1948.
- MUSGRAVE, A. W.: Wavefront Charts and Raypath Plotters, *Quarterly of the Colorado School of Mines*, Vol. 47, No. 4, October 1952.
- NETTLETON, L. L.: *Geophysical Prospecting for Oil*, McGraw-Hill, New York, 1940.
- RICKER, N.: Forms and Laws of Propagation of Seismic Wavelets, *Proceedings of the World Petroleum Congress*, 1951. *Geophysics*, XVIII, 1, January 1953.
- RIZNICHENKO, G. V.: Geometrical Seismology of Stratified Media, *Transactions of the Institute for Theoretical Geophysics*, II, 1946.
- THORNBURGH, H. R.: Wave-front Diagrams in Seismic Interpretation, *Bull. Am. Assoc. Petroleum Geologists*, Vol. 14, No. 2, February 1930.

QUANTITATIVE STUDIES CONCERNING THE VERTICAL GRADIENT AND SECOND DERIVATIVE METHODS OF GRAVITY INTERPRETATION *

BY

OTTO ROSENBACH **

ABSTRACT

In the first part of the present paper we shall investigate the possibility of localising highly situated inclined faults with the aid of the vertical gradient and the second derivative in the direction of the vertical. Since these quantities have been computed from gravity values by means of formulae of approximation we shall have to study the question as to their applicability for possible quantitative interpretation. Particular caution should be exercised when making the usual comparison with theoretical test examples. For three effects have to be taken into account which result from the application of the formulae of approximation:

- 1) The extreme values appear more or less smoothed out,
- 2) Extremal abscissae are being displaced,
- 3) The results are influenced by the orientation of the grid which forms the basis of the calculation.

For a practical instance it was possible to locate a well under troublesome circumstances. This well is situated on the downthrown side of an inclined fault, the depth of the upthrown side being known as a result of another well.

We shall show in the second part of the present paper how small, deeply situated structures may be recognised in the diagrams of the vertical gradient and of the second derivative. In the case of two practical instances the effect of these structures is rendered unrecognisable in the isogam map in view of regional influences. The results according to the formulae of Baranov, Elkins and Rosenbach are contrasted with each other.

The quantitative considerations which will be discussed in the present paper have resulted from a series of practical gravimetric investigations in the Rhine valley between Worms and Mainz. The relevant measurements were taken during the time between the autumn of 1952 and the following spring. Fig. 1 shows a section of the isogam map. The gravity anomalies reveal an increase as we pass from the East to the West, and exhibit distinctly the Western main fault of the Rhine Graben in view of the close concentration of the isogams. Within the Graben itself the layers rise sharply from the South towards the North, while they assume an extended raised position in the Eastern centre of the diagram. Two regional effects are therefore superimposed above each other, which prevent us from recognising the gravimetric effect of smaller

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structures. It is in connection with this survey that we propose to discuss such quantitative considerations which would possibly enable us to

- 1) localise as exactly as possible the main fault within the region I, and to
- 2) recognise minor structures within the Graben in the regions II and III.

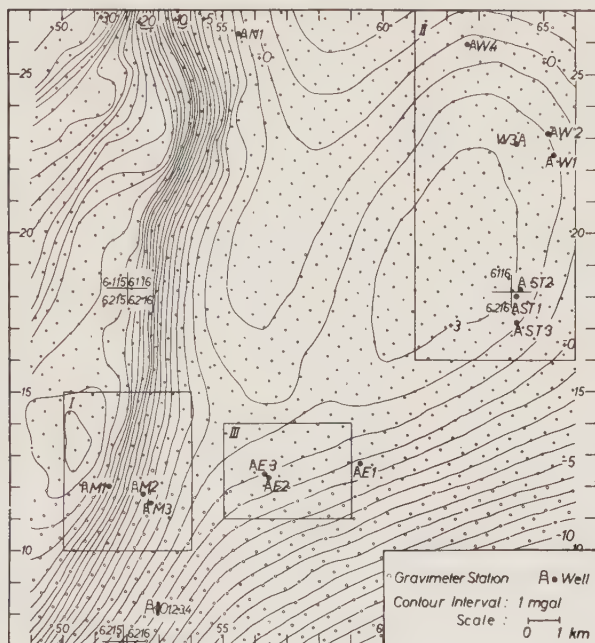


Fig. 1. Worms Area — Bouguer Anomalies.

In the course of this discussion we shall use the vertical gradient as well as the second derivative of gravity in the direction of the vertical. It is well known that both these quantities may be derived approximately from the Bouguer anomaly, regional influences being eliminated to a large extent. In all our considerations we shall contrast the results corresponding to three formulae:

- 1) the vertical gradient, derived according to Baranov,
- 2) the second derivative, derived according to the standard formula of Elkins,
- 3) the second derivative, derived according to a formula given by Rosenbach.

Using the point configuration of Elkins (fig. 2) for a quadratic grid with spacing s these formulae appear to be as follows:

$$\langle 1 \rangle g_z^P \approx \frac{1}{s} \left\{ 23,0518 g^P - 4,1587 \sum_{i=1}^4 g_i^A + 0,6287 \sum_{i=1}^4 g_i^B - 1,1165 \sum_{i=1}^8 g_i^C \right\} \cdot 10^{-9} \text{ cgs} \quad (\text{Baranov})$$

$$(2) g_{zz}^P \approx \frac{100}{62 s^2} \left\{ 44 g^P + 4 \sum_{i=1}^4 g_i^A - 3 \sum_{i=1}^4 g_i^B - 6 \sum_{i=1}^8 g_i^C \right\} \cdot 10^{-15} \text{ cgs (Elkins)}$$

$$(3) g_{zz}^P \approx \frac{100}{24 s^2} \left\{ 96 g^P - 18 \sum_{i=1}^4 g_i^A - 8 \sum_{i=1}^4 g_i^B + \sum_{i=1}^8 g_i^C \right\} \cdot 10^{-15} \text{ cgs (Rosenbach)}$$

when s and the Bouguer anomaly g are expressed in terms of kms and mgals respectively. — For the purpose of practical calculation s was chosen to be 1 km.

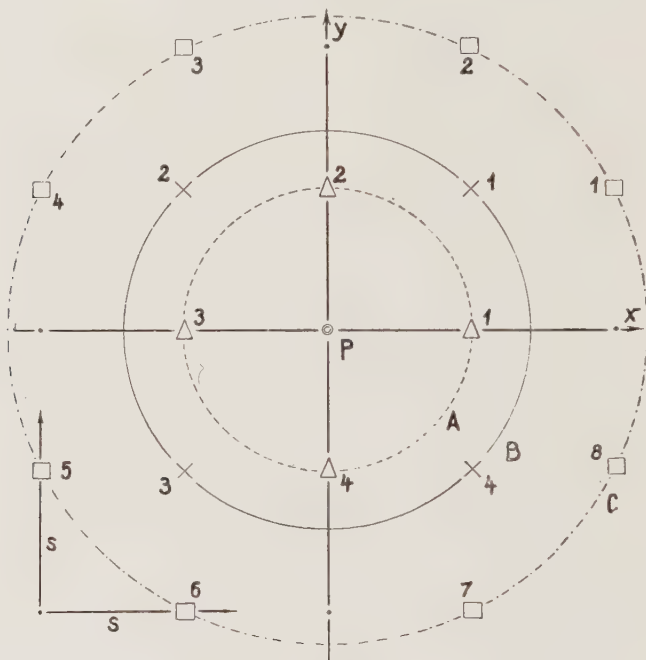


Fig. 2. Point Configuration of Elkins for a Quadratic Grid.
The formulae (1), (2), (3) are based on this configuration.

Let us now turn to the first problem, namely the localisation of the main fault. — It is known of the area under investigation that the gravity anomalies are largely conditioned by the difference in density between the Lower Permian and the Tertiary within the Graben. The lower Permian is encountered in the well Mettenheim 1 (M 1) to the West of the main fault at a depth of 200 m below sea-level. Within the Graben itself the Tertiary reaches a depth of an order of magnitude of 2000 m below sea-level; this is followed by the Lower Permian.

In the course of this investigation there arose the problem of applying the gravimetric results of the region I to the localisation of a bore hole. The well Mettenheim 2 (M 2) had been discontinued at an earlier date, having reached

the Upper Miocene at a depth of approximately 800 m below sea-level. It was required that the new well should reach the Tertiary basis within the Graben as close as possible to the main fault, without touching the latter. Certainly it will seem surprising that gravimetric results were used to a considerable extent in solving this problem. There was however no alternative, since the reflection seismic measurements could only be carried out to within the vicinity of the well Mettenheim 2 (M 2). A further continuation towards the West was prevented by vineyards situated there.

A glance at the isogam map will show us that two gravimetric effects are superimposed on each other just in the area of the wells Mettenheim 1 and 2 (M 1, M 2): firstly the increase in gravity, due to the main fault, and secondly the increase in gravity from the South to the North due to the corresponding rise of the layers within the Graben. It would be difficult to distinguish between these two effects by means of the usual methods for the determination of the residual anomaly. For this as well as other reasons preference was given to the second derivative, after which the vertical gradient was evaluated. At the time when the boring was to be localised, namely in the beginning of march 1953, the second derivative as derived only by formula (3) was known. In order to solve our problem we proceeded as follows: The main fault was regarded as being chiefly a so-called two-dimensional mass deposit, namely an inclined fault between the Lower Permian and the Tertiary. In this case the strike of the fault is given by the direction of the null-curve of the second derivative, i.e. the curve along which the second derivative vanishes. A profile of the second derivative normal to the strike, which is shown in fig. 3 served to locate this fault. This curve was obtained as a prototype of the influence of the fault by averaging over four actual profiles, of which only a few points are represented here. The relative orientation of these profiles was subject to the null-curve of the second derivative. The prototype of the profile of the second derivative thus obtained exhibits a distinct asymmetry in the distribution of values relative to the null-point. This indicates that the fault is inclined towards the East as is evident from the bordering diagram. Here the theoretical progression of values of the second derivative corresponding to three faults of different inclinations is represented. In our actual case the value $t = 200$ m corresponds to the depth of the Lower Permian according to the well Mettenheim 1 (M 1). From this diagram we conclude that the ratio of the two extreme values may serve to give a measure of the angle α of inclination. Besides, the null-point is the further away from P, the smaller the angle of incidence of the fault. Accordingly it is now possible to determine within certain limits the inclination α by means of the curve drawn on the left and using the ratio of the extreme values, and furthermore to determine the position of the upper edge Q of the disturbing plane using the null-point. On applying this process the following factors have to be taken into account:

- 1) Caution should be exercised when comparing the second derivative as calculated approximately with the theoretical curves, for the formula of

approximation cuts down peak values. This fact was taken into account in our case.

- 2) Further theoretical curves show that variations of T after approximately 1000 m do not possess any practical influence on the progress of the curves. This method therefore yields a practical determination of the fault only down to a depth of $T \approx 1000$ m. If it is applied extrapolatorily to higher vertical displacements, as has been done here, it will lead to correct results only under the condition that the disturbing surface be plane, i.e. under the condition that QR be a straight line in fig. 3.

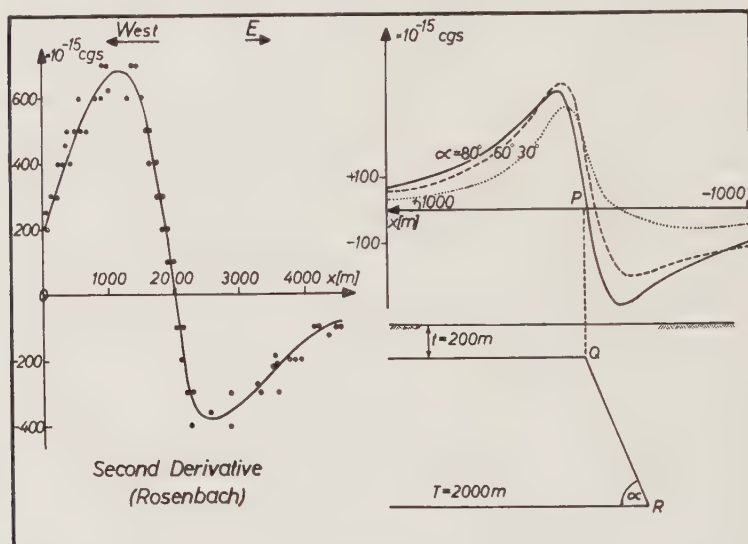


Fig. 3. Mean Profile of the Second Derivative for Region I of Worms Area, Contrasted with Theoretical Profiles for Inclined Faults.

On the basis of these assumptions and considerations the well Mettenheim 3 (M 3) was begun. This well was finished recently and has encountered the Tertiary basis at a depth of 1800 m, without striking the main fault. — This result may well be regarded with gratification, although favourable circumstances will certainly have their share in this. At present it is not known if too much caution had been exercised in fixing the position of the bore hole.

The problem which we have discussed so far, for the solution of which very little time had been available, gave rise to further considerations, which we propose to treat below.

First of all it is shown in fig. 4 how the prototypes of the curves of influence for the vertical gradient and the second derivative according to Elkins will appear. These curves also exhibit a distinct asymmetry relative to their null-points. Thus without doubt they could be used in a manner analogous to that described above.

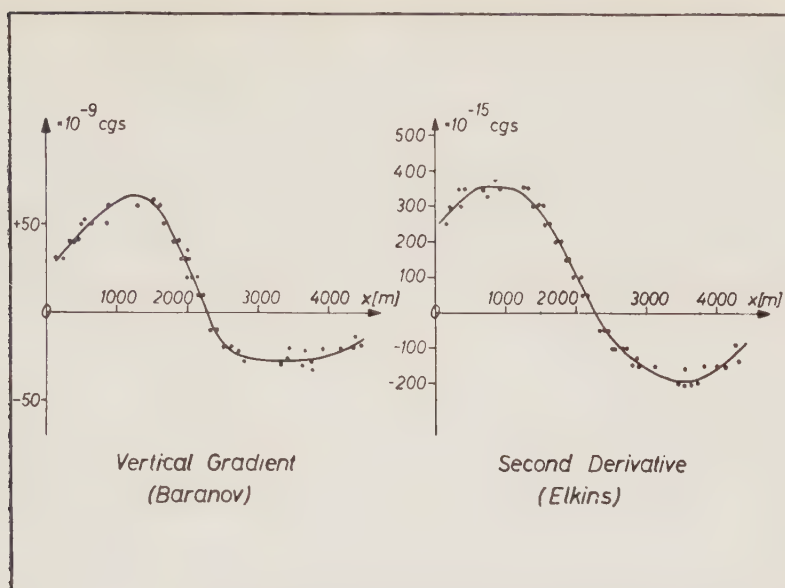


Fig. 4. Mean Profiles of the Vertical Gradient and of the Second Derivative for Region I of Worms Area.

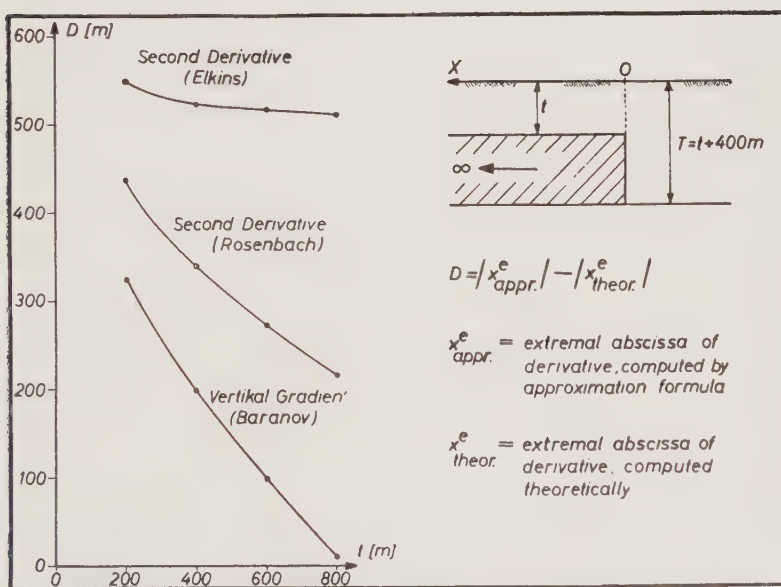


Fig. 5. Displacement of Extremal Abscissae of Derivatives Computed Approximately for Vertical Faults.

Furthermore, the following phenomenon will be of significance in this connection: A displacement of extrema occurs in the case of the curves calculated approximately. In instances of practical interest the extrema are further distant from the null-points of the vertical gradient and the second derivative when calculated approximately than when calculated theoretically. The curves thus obtained are flatter than those calculated theoretically, not only as a result of the cutting down of peak values but also in view of the displacement of the extrema. Fig. 5 will give an impression of the order of magnitude of this displacement for the case of vertical faults of thickness 400 m at different depths. The distance D between the extremal abscissa $x_{\text{appr.}}^e$, calculated approximately and the extremal abscissa $x_{\text{theor.}}^e$, calculated theoretically is represented by the ordinate.

It is easy to determine $x_{\text{theor.}}^e$ from the roots of the equations $dg_z(x)/dx = 0$ and $dg_{zz}(x)/dx = 0$, the functions $g_z(x)$ and $g_{zz}(x)$ being well-known. For the purpose of calculating $x_{\text{appr.}}^e$, the quadratic grid with a spacing of 1 km was oriented such that one of the directions of the grid-lines coincided with the strike of the fault. Differentiating the formulae of approximation (1), (2), (3) with respect to x , the zeros of the differential coefficients thus obtained are the corresponding values $x_{\text{appr.}}^e$. Since these values cannot be expressed explicitly in terms of t and T the former were determined graphically.

For highly situated faults D is found to be largest for each of the three formulae under consideration. This fact has the following significance for the case of the localisation of an inclined fault as described here: For the theoretical curves the maximum is sharp, whereas the minimum is shallow (cf. fig. 3). The displacement of extreme values which must necessarily occur when formulae of approximation are being used will be greater in the vicinity of the maximum than in the vicinity of the minimum. In practice, however, the influence curves are determined by connecting discrete values. If none of these values is sufficiently close to zero, the irregular displacement of the extrema will cause also a displacement of the null-point in the direction of the maximum. Since the null-point serves to determine the upper edge Q of the fault (cf. fig. 3), a consequent displacement of the latter would result.

Finally we have to investigate in this connection as to how far our results are influenced by the orientation of the point grid, which was used in our formulae of approximation. Fig. 6 will serve to enlighten us on this point in the case of a vertical fault. Let φ be the angle between the strike of the fault and one of the directions of the grid-lines. The graphical representations then show the vertical gradient and the second derivative for the angles $\varphi = 0^\circ$, 15° , 30° and 45° ; due to symmetry the cases $\varphi = 60^\circ$, 75° and 90° are thus also dealt with. Every one of these diagrams exhibits an influence of the orientation of the grid on our results; the marked relative dispersion of the maxima of the second derivative derived according to Elkins and of the vertical gradient are however remarkable. — With respect to our practical problem of localising an inclined fault we may therefore conclude: The ratio of the extreme values, which was a measure of the inclination α (cf. fig. 3), may also be

dependent on orientation; for it is not to be expected that the relative dispersion of the maximum and minimum values relative to those of a fixed curve, e.g. for $\varphi = 0^\circ$, would be the same in each case. But this implies a further uncertainty factor in the localisation of an inclined fault, which can, however, be eliminated to a considerable extent by studying the influence curves of suitable test examples calculated theoretically as well as approximately.

Up to the present our investigations were concerned with the vertical gradient and the second derivative for faults which were situated not too deeply; our starting point was a problem which cropped up in practice in the region I

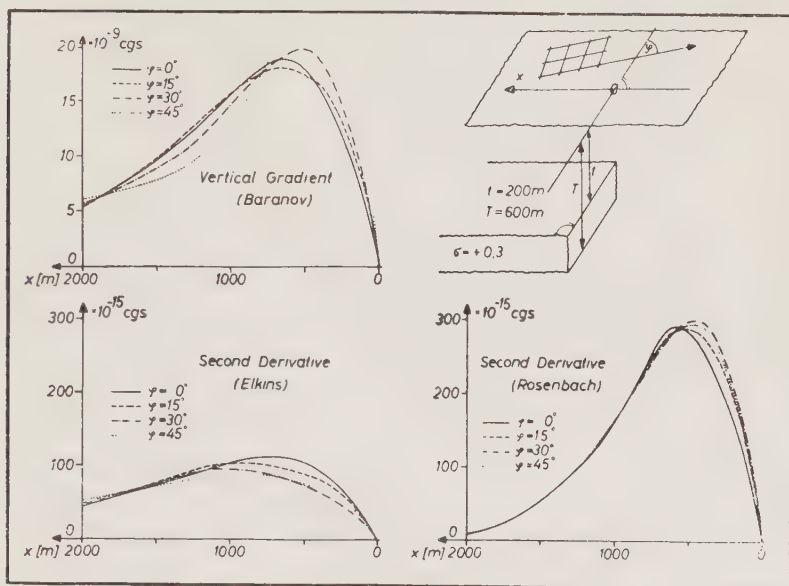


Fig. 6. Dependence of the Derivatives Calculated Approximately on the Orientation of the Grid for a Vertical Fault.

of fig. 1. The results presented here show that under given circumstances one may risk a quantitative exploitation of the derivatives evaluated from the Bouguer-Anomalies by means of formulae of approximation, but strict caution should be exercised.

In contrast to the main fault with a high vertical displacement and an up-thrown side at a low depth in the region I we shall discuss how small, deeply situated structures in the interior of the Graben are recognisable in the maps of the vertical gradient and the second derivative. Let us therefore turn to the regions II and III of fig. 1 in which the isogams obviously do not exhibit any structural indications.

In fig. 7 the results for the region II according to the formulae of Baranov,

Elkins and Rosenbach are contrasted with each other. In each case a relative high appears clearly in the South, this high belonging to the Stockstadt structure, which had been found seismically. The diagram in the centre shows only a single high in the North, whereas two highs appear in the two lateral diagrams. Reflection seismic measurements confirm the true existence of two separate highs. — Theoretically it is easily seen why the formula of Elkins cannot resolve these smaller structures. For the numerical solutions of this formula are influenced to a large extent by the gravity values corresponding to points at a distance of $\sqrt{5} \text{ km} \approx 2,2 \text{ km}$ from the point for which the



° Points of the quadratic grid on
which the calculation is based

A • Well

Fig. 7. Region II of Worms Area. Vertical Gradient and Second Derivative.

calculation is being carried out. Since the highs only have a diameter of the order of magnitude of 1 km, the distance between their centres being approximately 2,5 km, it is not surprising that they do not appear separated from each other in the central diagram.

It is not necessary to enter into a discussion of the theoretical reasons for this characteristic behaviour of the formula of Elkins. This has already been done in the reply to a remark made by Mr. Peters and Mr. Elkins concerning a paper of the author on the second derivative. This reply also contains two diagrams of the region III (fig. 1) of the area under consideration, contrasting the second derivatives as calculated according to Elkins and Rosenbach. To this contrast we may add the vertical gradient in fig. 8 for the sake of completeness. Here also the relative high which is clearly recognisable in nos. 1 and 3, is structurally conditioned and has been confirmed seismically.

The explanation why the high is missing in no. 2 is the same as the one given just now.

Without entering into further examples contained in the Worms area we may conclude with the following remarks which might be of general interest: The inhomogeneities of the density, which cause the highs of the derivatives in the regions II and III, are due to local, relative weak high positions of the layers. It may well be regarded as gratifying that it is possible to recognise this

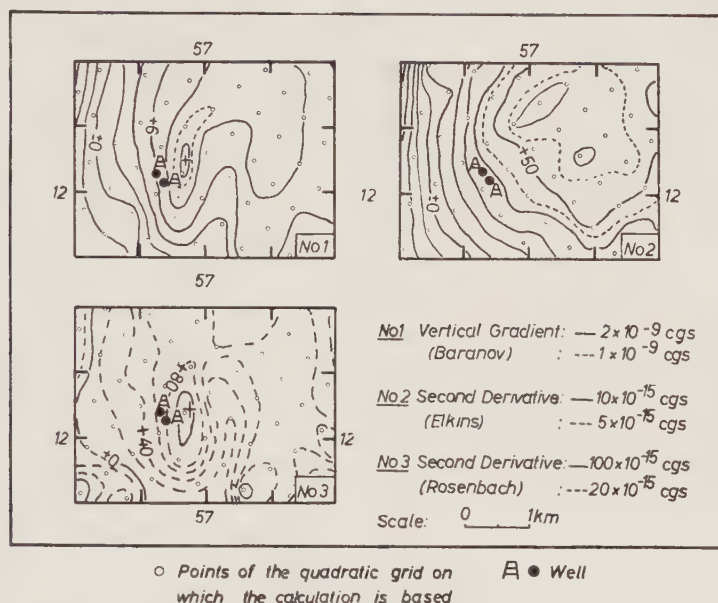


Fig. 8. Region III of Worms Area. Vertical Gradient and Second Derivative.

state of affairs in the manner explained above. However, the following points should be noticed:

- 1) The number of measuring stations per unit area has to be chosen suitably;
- 2) A suitable computation formula must be chosen;
- 3) The Bouguer-Anomalies at the points of a quadratic grid enter the calculation; these have to be determined from the actual data by interpolation.

This interpolation has to be carried out with great care when its results are being applied to sensitive formulae.

It is safe to say that the success or the failure of an investigation of this kind may well depend on whether sufficient heed is paid to these requirements.

ACKNOWLEDGMENTS

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REFERENCES

- BARANOV, V.: Calcul du Gradient Vertical du Champ de Gravité ou du Champ Magnétique Mesuré à la Surface du Sol. *Geophysical Prospecting*, Vol. I, 1953, 171-191.
- ELKINS, THOMAS A.: The Second Derivative Method of Gravity Interpretation. *Geophysics*, Vol. XVI, 1951, 29-50.
- ROSENBAACH, O.: A Contribution to the Computation of the Second Derivative from Gravity Data. *Geophysics*, Vol. XVIII, 1953, 894-912.

ON THE PROPAGATION OF SEISMIC WAVES IN A SOLID BODY WITH ELASTIC AFTERWORKING *

BY

H. MENZEL **

ABSTRACT

The different equations of elasticity concerning the departure of the behaviour of rocks from perfect elasticity are discussed. The theory of elastic afterworking and its significance for the propagation of elastic waves is studied in detail. It is found that this theory does not explain the observations on seismic waves in exploration geophysics so well as the theory of viscoelasticity suggested by Ricker.

It is a well-known fact, that the observations of seismic waves in the earth cannot be explained in all their essential features, if one considers the rocks as perfectly elastic bodies. For a long time seismologists have examined the question as how one must alter the fundamental equations of elasticity theory in order to account for the departures of rocks from perfectly elastic behaviour. Jeffreys (1917) following a proposal of Larmor and an investigation of Maxwell has suggested two differential equations, which in a simplified form are as follows:

$$2 \mu \varepsilon = S + \frac{1}{t_1} \int_{-\infty}^t S d\tau \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

$$2 \mu \left(\varepsilon + t_2 \frac{d\varepsilon}{dt} \right) = S \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

In these equation S is a shearing stress and ε the corresponding component of the straintensor. The first equation denotes Jeffreys equation of elastico-viscosity, the latter the equation of firmoviscosity. Hosali, Gutenberg and Schlechtweg have continued these investigations and later on many authors have considered the propagation of seismic waves in a body the elastic behaviour of which may be represented by equation (2). But most of them denote such a body as a viscoelastic medium. The change in the shape of seismic waves in a viscoelastic body has been, for the time, examined by Sezawa. He, however, considered chiefly the surface waves of earthquakes.

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The case of elastic waves caused by explosions in a viscoelastic body has been dealt with by Ricker in several papers. He states, that his theoretical results are in good agreement with the observations in exploration geophysics. Recently, however, there have been serious objections against the usefulness of viscoelastic theory.

In 1949 Nakamura, in a research, noticed that this theory stands in disagreement with the observations of elastic behaviour of the earth. He states that the earth behaves as a perfectly elastic body against fast changing disturbances and as a viscous fluid against very slowly changing disturbances, while the differential equation of viscoelasticity demands just the opposite behaviour. Jeffreys also states in the third edition of his book "The Earth", that there is no solid body the behaviour of which may be described by the theory of viscoelasticity. Instead of equation (2) Nakamura suggests an equation, which in the case of a simple shearing stress S and the corresponding component of strain is as follows:

$$aS + \frac{dS}{dt} = 2(\mu'\epsilon + \mu \frac{d\epsilon}{dt}) \quad . \quad . \quad . \quad . \quad . \quad (3)$$

Already in 1937 Sokoloff and Skriabin have proposed another fundamental equation. These scientists considered the elastic afterworking and obtained, following investigations of Boltzmann, Wiechert, Derjaguine and others, an equation, which in a simple form is as follows:

$$2\mu\epsilon - 2\beta\mu \int_{-\infty}^t \epsilon(\tau) e^{-(\alpha + \beta)(t - \tau)} d\tau = S \quad . \quad . \quad . \quad . \quad (4)$$

The research of Sokoloff and Skriabin is very important because these

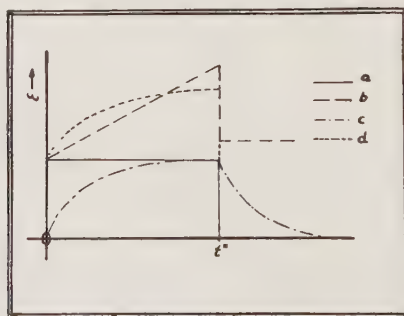


Fig. 1.

authors have checked their theoretical results by numerous laboratory trials with samples of rocks. They state a good agreement between these experiments and the theory.

Fig. 1 represents the behaviour of a solid body either perfectly elastic

(Fig. 1a) or according to one of the fundamental equations quoted above. Here it has been assumed, that at a time $t = 0$ suddenly a constant shearing stress appears and suddenly disappears at $t = t^*$. In the case of perfectly elastic body the deformation at once assumes a finite value with the beginning of the stress. This deformation remains constant as long as the stress acts and becomes zero again, as soon as the stress disappears. Fig. 1b shows the behaviour according to equation (1). With the beginning of stress a deformation like that of a perfectly elastic body appears. But this, instead of remaining constant, increases with time, i.e. the body flows. After the shearing stress is removed, the deformation at once decreases by an amount which is equal to the deformation in the case of perfect elasticity and then remains constant. That means, the body is plastic. Fig. 1c represents the behaviour of a visco-elastic body. With the beginning of stress follows no deformation of a finite value suddenly, but the deformation creeps to the value in case of perfect elasticity, exactly speaking only in an infinite time. With the removal of stress

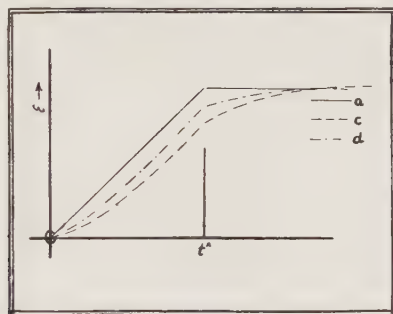


Fig. 2.

there is no sudden decrease of deformation to a finite value, but it gradually decreases to zero, of course, to be exact, only in an infinite time. The behaviour of a rock which is described by differential equation of Nakamura is quantitatively the same, as is described by the fundamental equation of Sokoloff and Skriabin. It has been drawn in Fig. 1d. With the beginning of shearing stress there is a deformation like that in case of perfect elasticity. But, instead of remaining constant like in this case, it increases gradually to a finite limit. With the removal of stress the deformation decreases at once by the amount of perfectly elastic deformation and then creeps back to zero.

The behaviour represented by Fig. 1b will not be further discussed here. One cannot suggest, that rocks are by no means plastic, but considering the stresses important in seismology, such a behaviour is not likely. Therefore it may be justified, to restrict the discussion of the equations two to four.

The experiments by Sokoloff and Skriabin have been about bending and torsion. In these experiments the stress increases linearly from zero to a finite limit. Fig. 2 shows the behaviour of a rock under such a stress according to

we can transform equation (5a) into (5b). Thus the equation of Sokoloff and Skriabin is a special case of the equation of Nakamura, but it may be worthwhile to mention that the latter equation does not contain as a special case the equation of viscoelasticity.

Now it is often stated in elasticity theory that every solid body behaves as a perfectly elastic one against hydrostatic pressure. Jeffreys has also mentioned this in the latest edition of his book "The Earth". If one agrees to this point, which I will do here with some reservation, it gives another relation between the constants in the theory of Nakamura. From (5a) it follows:

$$(a + \frac{\partial}{\partial t}) \sigma_{jj} = \left[(3\lambda' + 2\mu') + (3\lambda + 2\mu) \frac{\partial}{\partial t} \right] \varepsilon_{jj} \quad (5d)$$

If we assume

$$\varepsilon_{jj} = 0 \text{ at } t = 0 \quad (7)$$

and if we further assume that $3\lambda' + 2\mu'$ has a positive value and that σ_{jj} will not be infinite at $t = -\infty$, then we have:

$$\varepsilon_{jj} = \frac{1}{3\lambda + 2\mu} \left[\sigma_{jj} + (a - \frac{3\lambda' + 2\mu'}{3\lambda + 2\mu}) \int_{-\infty}^t \sigma_{jj} e^{-\frac{3\lambda' + 2\mu'}{3\lambda + 2\mu}(t-\tau)} d\tau \right] \quad (8)$$

In perfectly elastic theory the integral term on the right hand of equation (8) vanishes and therefore we get the condition:

$$a = \frac{3\lambda' + 2\mu'}{3\lambda + 2\mu} \quad (9)$$

The equation of Sokoloff and Skriabin opposes the assumption, that every body is to behave like an perfectly elastic one against hydrostatic pressure. It is not clear, why they do not regard it, while Derjaguine accepts this view in his theory which is the basis of the research by Sokoloff and Skriabin. When we modify the equation of these authors in such a way as to consider this view, we obtain:

$$\sigma_{ir} = \lambda \varepsilon_{jj} \delta_{ir} + 2\mu \varepsilon_{ir} + \beta \int_{-\infty}^t (\varepsilon_{jj} \delta_{ir} - 3\varepsilon_{ir}) e^{-\gamma(t-\tau)} d\tau \quad (10)$$

This equation is completely identical with that of Nakamura if one considers relation (9) and shall be accepted as fundamental equation for further investigation.

The equation of motion, following from (10), is:

$$\begin{aligned} \rho \frac{\partial^2 \mathfrak{S}}{\partial t^2} = & (\lambda + 2\mu) \text{grad div } \mathfrak{S} - \mu \text{rot. rot. } \mathfrak{S} - \\ & - \frac{\beta}{2} \int_{-\infty}^t (4 \text{grad div } \mathfrak{S} - 3 \text{rot. rot. } \mathfrak{S}) e^{-\gamma(t-\tau)} d\tau \quad (11) \end{aligned}$$

In this equation $\mathfrak{S}$ denotes the vector of displacement. Now, for the sake of simplicity, we will only consider plane dilatational waves. With x we denote the coordinate in the direction of propagation of the wave and u may be the component of displacement in this direction. Then the result of integration of equation (11) is:

$$U = \int_{-\infty}^{+\infty} A(\omega) e^{i\omega(t - K \frac{x}{a})} d\omega \quad . \quad . \quad . \quad (12)$$

and

$$K = \sqrt{\frac{\gamma + i\omega}{\gamma - 2\frac{\beta}{\rho a^2} + i\omega}}, \quad a^2 = \frac{\lambda + 2\mu}{\rho} \quad . \quad . \quad . \quad (13)$$

The function $A(\omega)$ will be determined by the boundary condition at $x = 0$. At this boundary $x = 0$ we will prescribe the normal pressure $N(t)$, which causes the seismic wave. We choose this normal pressure as follows:

$$N(t) = \begin{cases} 0 & -\infty < t < 0 \\ e^{i\omega_0 t} & 0 \leq t < +\infty \end{cases} \quad . \quad . \quad . \quad (14)$$

In this latter formula ω_0 shall not be restricted on real values, but the imaginary part of ω_0 shall not be negative, for $N(t)$ shall not increase to infinity in course of time. For a real value of ω_0 the source of the wave acts stationary and for a complex value of ω_0 the disturbance, which causes the wave, dies out with increasing time. If we represent $N(t)$, given by (14) by a Fourier-Integral, we obtain from (12) and (10):

$$A(\omega) = -\frac{1}{2\pi\rho a} \frac{K}{\omega(\omega_0 - \omega)} \quad . \quad . \quad . \quad (15)$$

The records of the geophones, mostly used in applied seismology, are approximately proportional to the velocity $\frac{\partial u}{\partial t}$ of any point. Therefore we will

consider $\frac{\partial u}{\partial t}$ and obtain from (12) and (15):

$$\frac{\partial u}{\partial t} = \frac{1}{2\pi i \rho a} \int_{-\infty}^{+\infty} e^{i\omega(t - K \frac{x}{a})} \frac{K}{\omega_0 - \omega} d\omega \quad . \quad . \quad . \quad (16)$$

In order to evaluate the integral in (16) we must determine the singular points of the integrand. These singular points consist of the pole $\omega = \omega_0$ and the branch points $\omega = \omega_1 = i\gamma$ and $\omega = \omega_2 = i(\gamma - 2\frac{\beta}{\rho a^2}) = i\eta\gamma$. The part of the imaginary axis between $\omega = \omega_1$ and $\omega = \omega_2$ is cut off from the complex ω -plane. Then K will be a unique function of ω and we can easily show

that $\operatorname{Re}(K) > 0$ holds. The evaluation of the integral succeeds with the help of Cauchy's theorem. For a sufficient large $|\omega|$, the value of K will be approximately 1 and the exponent of the e-function of the integrand becomes $i\omega(t - x/a)$. Suppose $t - x/a < 0$. Then we can shift the way of integration as far as we choose in the lower part of the ω -plane. The integrand will become as small as we like, i.e., the integral has the value zero. Therefore the wave is zero for $t < x/a$ and passes through the point x at the time $t = x/a$. The velocity of propagation of the wave is a . Now suppose $t - x/a > 0$. Indeed the integrand will be as small as we please, if we shift the path of integration sufficiently in the upper part of the ω -plane. But the way of integration must include the singular points, which all lie in the upper part of the ω -plane. Therefore the solution of the integral consists of two parts: 1) The integral over a circle around the pole. This part is equal to the residue of the integrand for the pole. 2) The integral along any way around the branch line. This latter way may be chosen arbitrarily, but it will be practical to choose it such, that it passes through a saddle-point of the integrand. The equation of saddle-points is:

$$\frac{d}{d\omega} [i\omega(t - K \frac{x}{a})] = 0 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (17)$$

One can easily show, that there are two saddle-points with $\operatorname{Re}(K) > 0$, that they lie on the imaginary axis of ω or, in the k -plane on the real axis and that the one of them lies above $\omega = \omega_1$, the other beneath $\omega = \omega_2$. Furtheron it is not difficult to demonstrate that the exponent of the e-function of (16) will be real but not positive in the saddle-points. Now we will choose the path of integration around the branch line in such a way, that it passes through the two saddle-points and that the exponent of the e-function of (16) is always real. It is a little cumbersome but, without much difficulty, one can find out that the integrand is limited along this path, with the only exception, when it passes through the pole. The position of the way depends upon the ratio $\frac{x}{at} = \tau$. The parameter τ may be assumed as being smaller than unity, because the integral disappears for $t - x/a < 0$. For a fixed x and increasing t the value of τ decreases towards zero. Furtheron τ cannot have negative values, for the consideration will be limited to positive values of x . Therefore $0 < \tau < 1$ holds. If we study the oscillation on a fixed point $x = x_0$, it is zero at $t < x/a$ and begins at $t = x/a$ as already stated. In this case we have $\tau = 1$. If t increases, τ decreases to zero. How is now the position of the way of integration around the branch line as a function of τ ? We will not demonstrate it, for this demonstration, though theoretically not difficult, is very laborious. The result is as follows (see Fig. 3): For τ nearly equal to 1 this path is a closed curve around the branch line at a great distance from the origin. As τ decreases, the area enclosed by this curve will become smaller and smaller.

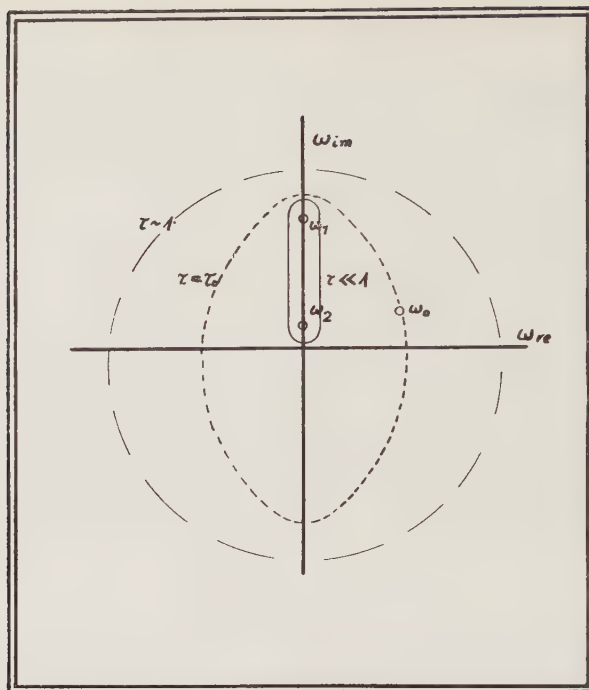


Fig. 3.

For τ nearly zero, it is a curve closely surrounding the branch line. For a certain value, say $\tau = \tau_0$, the way of integration will pass through the pole $\omega = \omega_0$. If $\tau > \tau_0$ the pole is enclosed by the path of integration and therefore does not contribute any portion to the value of the integral. When τ has become smaller than τ_0 , one must add the residue of the integrand for the pole to the value of the integral around the branch line. One can say: The part of the wave, which is represented by the residue of the pole appears in a point $x = x_0$ at the time $t = x_0/a\tau_0$, or, this part of the wave has the velocity of propagation $v = a\tau_0 < a$. If we denote it by u^* , we have:

$$\frac{\partial u^*}{\partial t} = -\frac{K_0}{\rho a} e^{i\omega_0(t - K_0 \frac{x}{a})}, \quad \frac{x}{a\tau_0} < t < \infty \quad . \quad . \quad (18)$$

and

$$K_0 = \sqrt{\frac{\omega_0 - \omega_1}{\omega_0 - \omega_2}} \quad . \quad . \quad . \quad . \quad . \quad (19)$$

Now we put:

$$t = \frac{x}{a\tau_0} + t' \quad . \quad . \quad . \quad . \quad . \quad (20)$$

Then it follows from (18):

$$\frac{du^*}{dt} = -\frac{K_0}{\rho a} e^{i\omega_0[t' - (K_0 - \frac{1}{\tau_0}) \frac{x}{a}]}, \quad 0 < t' < \infty \quad (21)$$

The frequency of this wave is represented by $\text{Re}(\omega_0)$, its damping by $\text{Im}(\omega_0)$, whereas its extinction, that is, the attenuation of its amplitudes is determined by $i\frac{\omega_0}{a}(K_0 - \frac{1}{\tau_0}) = \alpha_0$. It can be shown, but again it shall not be demonstrated, that α_0 is always real and positive. Putting

$$K_0 = R_0 e^{i\psi_0} \quad (22)$$

we obtain finally:

$$\frac{\partial u^*}{\partial t} = \frac{R_0}{\rho a} e^{-\alpha_0 x} e^{i\omega_0(t' + \psi_0 + \pi)}, \quad 0 < t' < \infty \quad (23)$$

In order to get the complete solution we must add to $\frac{\partial u^*}{\partial t}$ the integral around the branch line. This integral can be expanded in series of Bessel-functions. Numerical estimates, however, have had the result that mostly this portion of the solution is not very significant. Therefore its evaluation may only be indicated. For having a closed path of integration, the factor before the e-function of the integrand can be expanded into Fourier-series. This holds true for $\tau \neq \tau_0$. It is even possible, to obtain such an expansion into Fourier-series, in which the exponent of the e-function is of the form $\xi_0 + \xi_1 \cos \varphi$. Then we obtain:

$$\oint e^{i\omega t(1-\tau K)} \frac{K}{\omega_0 - \omega} d\omega = \int_0^{2\pi} e^{t(\xi_0 + \xi_1 \cos \varphi)} \sum_{v=-\infty}^{+\infty} P_v e^{i v \varphi} d\varphi =$$

$$= 2\pi e^{\xi_0 t} \sum_{v=-\infty}^{+\infty} i^v P_v J_v(-i\xi_1 t) \quad (24)$$

In this formula J_v denotes a Bessel-function of order v and the constant ξ_0 and ξ_1 have real and negative values, $|\xi_0|$ being greater than $|\xi_1|$.

As already stated, it is sufficient to study $\frac{\partial u^*}{\partial t}$ numerically in order to get an idea of the main feature of seismic waves according to equation (11). This has been done using the constants of dry sandstone determined by Sokoloff and Skriabin. The values of these constants are as follows:

$$a = 3,0 \text{ km/sec}; \quad \gamma = 3,68 \text{ sec}^{-1}; \quad n = 0,664$$

Two different cases have been dealt with. Firstly the case of stationary disturbance, i.e., $\text{Im}(\omega_0) = 0$. Secondly the case $\text{Im}(\omega_0) = \frac{100}{\pi} \text{Re}(\omega_0)$. In the

latter case the disturbance is strongly damped. Considering the imaginary part of $N(t)$ according to (14) and that of $\frac{\partial u^*}{\partial t}$ according to (23) we see that the disturbance is zero for $t = 0$ and increases rapidly to a maximum value, from which it decreases slowly. To be exact, the disturbance oscillates, but only the first extremum is of considerable amount. The further ones may be neglected. Therefore this case may serve as an example for the propagation of waves caused by explosions.

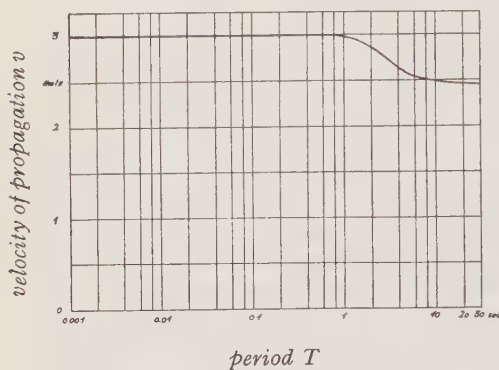


Fig. 4

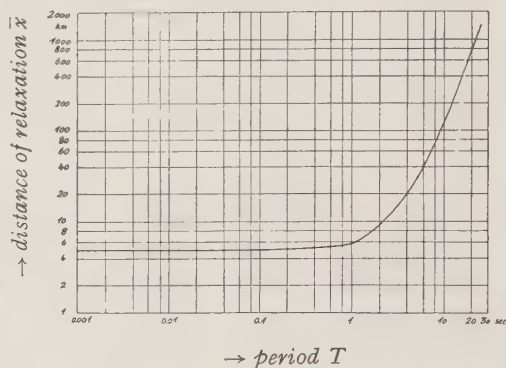


Fig. 5

The figures (4) and (5) represent the case of stationary disturbance. Fig. 4 shows the velocity of waves measured for example at the first extremum caused by stationary disturbances of different periods. For very short periods the velocity of wave is nearly constant and equal to a . For increasing periods the velocity decreases more or less slowly to a finite limit less than a . In Fig. 5 the distance of relaxation is presented as a function of period, being the distance, at which the amplitude of the wave is the fraction $\frac{1}{e}$ of the original

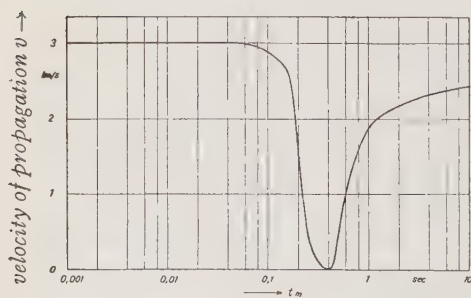


Fig. 6

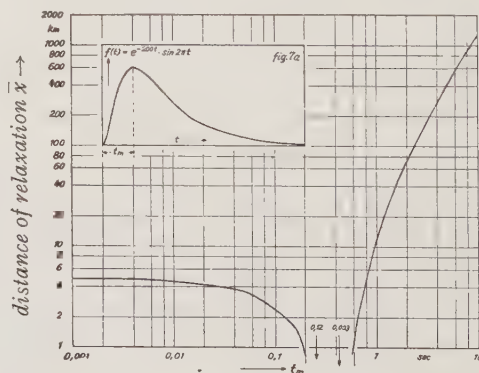


Fig. 7

value. We may see in this figure, that waves of long period attenuate considerably less than short period waves.

More remarkable is the second case. Fig. 6 represents the velocity of wave propagation, as function of t_m which is the time at which the disturbance reaches its maximum value. (See Fig. 7a). As in the former case the velocity of wave propagation is nearly constant and is equal to a for short period waves and reaches a finite value less than a for long period waves. However contrary to the former case the decrease of velocity with increasing t_m is not monotone but has a minimum value with very small values in a certain range of t_m . In this range, which of course depends on the constants γ and n , the waves cannot penetrate the medium well. The statement is also established by Fig. 7, which shows the distance of relaxation as function of t_m . In the same range of t_m , in which the velocity of propagation decreases considerably, the distance of relaxation becomes extremely small, i.e. the medium is practically opaque for waves caused by such disturbances. For very small and very large values of t_m the picture is similar to that of the former case of stationary disturbance.

Exactly speaking, we cannot state that in the range of t_m , in which the amplitudes of $\frac{\partial u^*}{\partial t}$ decrease very rapidly, the medium is opaque. To determine that we should evaluate also the integral around the branch line. In fact this calculation is very cumbersome. It has been estimated, that also in this case, the value of $\frac{\partial u}{\partial t}$ is negligible. The physical meaning of this fact is that the energy of wave is spread over a great interval of time. Therefore the amplitudes are extremely small.

If we now want to compare the theory of elastic afterworking with observations on seismic waves, we find that our knowledge of the attenuation of amplitudes is very poor. However, it seems that at least for short period waves there is no agreement between this theory and observations. For the waves in exploration seismology the theory of viscoelasticity seems to be far better. Thus, I am not inclined to accept the assumption of Nakamura nor that of Sokoloff and Skriabin. Now we face the dilemma that while the laboratory experiments are well explained by the theory of elastic afterworking, they contradict the theory of viscoelasticity. On the other hand the observations on seismic waves oppose the theory of elastic afterworking and agree, according the statement of Ricker, with the theory of viscoelasticity.

Perhaps it would be possible to solve this problem by generalising equation (4) in such a way, that we put instead of (4)

$$2\mu\varepsilon - 2\mu \sum_{v=1}^n \int_{-\infty}^t \beta_v \varepsilon(\tau) e^{-(\alpha_v + \beta_v)(t-\tau)} d\tau = S \quad . \quad (25)$$

Such equations have already been suggested by Wiechert. Or we should try to combine the equations (2) and (3), as Jeffreys did with the equations (1)

and (2). But first of all we need a lot of exact and systematical observations of the attenuation of amplitudes of seismic waves.

REFERENCES

- Derjaguine, B.: "Propagation des ondes élastiques dans les milieux non idéalement élastiques". Beitr. z. angew. Geoph. 4, 1934, p. 457.
 Gutenberg, B. und Schlechtweg, H.: "Viskosität und innere Reibung fester Körper". Phys. Zeitschr. 31, 1930.
 Hosali, M.: "On seismic waves in a Viscoelastic Earth". Proc. Roy. Soc. London 104, 1923.
 Jeffreys, H.: "The Viscosity of the Earth". Monthl. Not. Roy. Astr. Soc. 77, 1917.
 Jeffreys, K.: "The Earth", 3. Aufl. p. 11 u. p. 40.
 Nakamura, S. T.: "On viscoelastic medium", Sci. Rep. Tohoku, Un. 1, 1949.
 Ricker, N.: "The form and laws of Propagation of seismic wavelets". Section I. Reprint 11. 1951. E. J. Brill, Leiden.
 Sezannes, K.: "On the decay of waves in a viscoelastic solid body". Bull. Earthqu. Res. Inst. Tokyo III. 1927.
 Sokoloff, P. T. u. Skriabin, V. J.: "Experimental and theoretical investigations on dispersion and absorption of elastic waves". Gerl. Beitr. 49, 1937.

DISCUSSION

Mr. KREY: Hängt die Auslöschungszone in einer der letzten gezeigten Abbildungen von der Steilheit; oder anders ausgedrückt von der Halbwertszeit der für $x = 0$ vorgegebenen Verschiebung ab? und wie?

Mr. MENZEL: Ja, die Art der Abhängigkeit lässt sich nicht an diesem Ort so rasch angeben.

Mr. JUNG: Menzel's Theorie hat 4 Elastizitätskonstanten λ , μ , λ' , μ' . Es gibt eine ältere Theorie von Gutenberg und Schlechtweg, die nur 3 Elastizitätskonstanten enthält. Ist diese Theorie also als veraltet anzusehen oder nicht, und in welcher Beziehung steht sie zu Ihrer Theorie?

Mr. MENZEL: Diese Theorie ist nicht veraltet. Ich habe 4 Konstanten, aber es gibt eine Beziehung zwischen ihnen.

Mr. ROSENBACH: Sie haben kürzlich eine Arbeit über die Entstehung seismischer Wellen publiziert und dort den Fall des rein elastischen Mediums behandelt. Können Sie schon entsprechende Resultate für ein Medium mit elastischer Nachwirkung mitteilen.

Mr. MENZEL: Ich habe diesen Fall auch berechnet. Er liefert aber nicht wesentlich andere Ergebnisse als der hier behandelte Fall ebener Wellen.

Mr. ROSENBACH: In diesen theoretischen Untersuchungen wird der physikalische Vorgang der Wellenausbreitung ins Auge gefasst. Es können damit über die übliche geometrische Optik hinausgehende Anhaltspunkte für die Auswertung seismischer Messungen geliefert werden. Es wäre für die angewandte Seismik von grossem Interesse wenn eine Theorie des visko-elastischen Mediums mit elastischer Nachwirkung, die Wellenausbreitung bei der Reflexion und die dabei auftretenden Absorptionsbande angeben könnte.

Mr. MENZEL: Da gibt es noch grosse mathematische Schwierigkeiten. Die Grösse der Konstanten ist auch nicht bekannt.

ZUR BESTIMMUNG VON WELLENGESCHWINDIGKEITEN AUS REFLEXIONSSEISMISCHEN MESSUNGEN *

VON

H. DÜRBAUM **

Bekanntlich ist die Bestimmung seismischer Geschwindigkeiten eines der wichtigsten Probleme in der Reflexionsseismik. Aus Bohrlochmessungen lassen sich Wellengeschwindigkeiten bis auf etwa 1 % genau bestimmen und mit einigen Abänderungen, die wegen wechselnder Mächtigkeit und Tiefenlage der Schichten notwendig werden, in einem mehr oder weniger grossen Umkreis um die Bohrung verwenden. In Gebieten ohne Tiefbohrungen ist man auf reflexions- und refraktionsseismische Messungen angewiesen. Dabei sind die aus Refraktionsmessungen gewonnenen Geschwindigkeiten in der Reflexionsseismik nur mit Vorsicht und starker Einschränkung zu verwenden.

Der Vorgang bei der Auswertung von Reflexionsseismogrammen für Geschwindigkeitsbestimmungen besteht aus

1. einer präzisen Festlegung der Zeit-Abstandskurve, die die Geophonzeit $\tau(x)$ in Abhängigkeit vom Abstand x zwischen Schusspunkt und Geophon wiedergibt, und

2. einer graphischen oder rechnerischen Ermittlung sogenannter Durchschnittsgeschwindigkeiten, aus welchen vielleicht noch Schichtgeschwindigkeiten näherungsweise berechnet werden.

Bei der Festlegung der Zeit-Abstandskurve — im folgenden nur noch kurz $\tau(x)$ -Kurve genannt — liegt die Schwierigkeit ausser im Erkennen der Einsatzeitpunkte der Geophone in der Anbringung einer brauchbaren Oberflächen- und Verwitterungskorrektur sowie einer Berücksichtigung von eventuellen Verfrühungen von Geophoneinsätzen durch Mischen der an den Geophonen eintreffenden Energien. Die Ermittlung der Geschwindigkeiten stützt sich auf die Annäherung der $\tau(x)$ -Kurve durch eine Hyperbel

$$\tau(x)^2 = \tau(0)^2 + 2Ax + Bx^2, \quad \dots \quad (1)$$

welche dadurch nahegelegt wird, dass im Falle einer einheitlichen Geschwindigkeit bis zu dem reflektierenden Horizont eine solche hyperbolische Beziehung exakt richtig ist. Die dann die Zeit-Abstandskurve wiedergebende Gleichung

$$\tau(x)^2 = \tau(0)^2 - \frac{2\tau(0)\sin\gamma}{v} + \frac{x^2}{v^2} \quad \dots \quad (2)$$

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(γ = Neigung des Horizontes, v = Schichtgeschwindigkeit bis zum Reflexionshorizont) verleitet nun aber vielfach dazu, einfach den in (1) noch unbestimmt gelassenen Koeffizienten B als das Reziproke des Quadrates einer sogenannten „Durchschnittsgeschwindigkeit“ bis zum Reflexionshorizont anzusehen und nach seiner mehr oder weniger genauen Bestimmung aus der Zeit-Abstandskurve entsprechend zur Konstruktion zu gebrauchen. Die meist benutzten Wege zu dieser Bestimmung sind Formeln wie

$$\bar{v}^2 = \frac{2x^2}{\tau(x)^2 + \tau(-x)^2 - 2\tau(0)^2} \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad (3)$$

oder

$$\bar{v}^2 = \frac{x}{\tau(x)\tau'(x) - \tau(-x)\tau'(-x)} \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad (4)$$

oder graphische Verfahren, die sich die Konstruktion der an einem Spiegel reflektierten Strahlen oder den sogenannten Wanneneffekt zunutze machen (Krousky, 1952).

Es soll hier dieses Vorgehen bei der Geschwindigkeitsbestimmung aus Reflexionsseismogrammen für den Fall untersucht werden, dass sich der Untergrund aus einer Folge von Schichten mit konstanten Schichtgeschwindigkeiten und ebenen Schichtgrenzen einheitlicher Streichrichtung zusammensetzt, die aber beliebige Winkel miteinander bilden dürfen, d.h. für den ebenen n -Schichtfall.

Die Annäherung der $\tau(x)$ -Kurve durch eine Hyperbel ist, wie an mehreren Beispielen gezeigt wird, in einer weiten Umgebung des Schusspunktes genau genug, um als Grundlage auch für die Gewinnung von Korrekturen für aus Langaufstellungen erhaltene Geschwindigkeiten dienen zu können. Die genaueste Annäherung für $\tau(x)$ in der Umgebung des Schusspunktes durch eine Hyperbel ist die nach dem quadratischen Gliede abgebrochene Taylorentwicklung von $\tau(x)$ am Schusspunkt $x = 0$. Wir wollen für unsere Untersuchungen diese Taylorentwicklung von $\tau(x)$ benutzen. Bekanntlich haben dann die in (1) unbestimmt gelassenen Koeffizienten die Bedeutung

$$A = \tau(0) \tau'(0) \quad B = \tau'(0)^2 + \tau(0) \tau''(0). \quad \cdot \quad \cdot \quad \cdot \quad (5)$$

Wie in einer früheren Arbeit gezeigt, gilt die Gleichung

$$\tau_n'(0) = -\frac{1}{v_1} \sin(\alpha_{1n}^\circ + \gamma_1), \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad (6)$$

wenn α_{1n}° der Einfallswinkel des an der n -ten Schichtgrenze in sich reflektierten Strahles an der ersten Schichtgrenze ist (γ_1 = Neigung der ersten Schichtgrenze). Entsprechend wird nun die zweite Ableitung der Laufzeitkurve am Schusspunkt berechnet; man erhält einen Ausdruck, in dem ausser den Schichtmächtigkeiten und -geschwindigkeiten die Winkel vorkommen, die der an der n -ten Schicht in sich reflektierte Strahl mit den Schichtgrenzen bildet.

Mit Hilfe der so gewonnenen Näherungsformel für die $\tau(x)$ -Kurve werden

dann das Verhalten der „Durchschnittsgeschwindigkeiten“ unter verschiedenartigen Bedingungen sowie Korrekturmöglichkeiten untersucht, eine Fortsetzung der Untersuchungen von Th. Krey über Brechungskorrekturen. Es ergibt sich u.a. die Möglichkeit, aus den „Durchschnittsgeschwindigkeiten“ bis zum n -ten und $(n-1)$ -ten Reflexionshorizont die Schichtgeschwindigkeit in der n -ten Schicht zu ermitteln. Im Falle paralleler Schichten werden die Formeln besonders einfach und lassen sich dann auch unter der Voraussetzung, dass das optische Brechungsgesetz auch im Kleinen für die Seismik gültig ist, auf den Fall stetiger Änderung der Geschwindigkeiten in den einzelnen Schichten verallgemeinern. Dadurch ist es umgekehrt wieder möglich, aus reflexionsseismischen Messungen Aufschluss über die Art der Veränderung der seismischen Geschwindigkeit mit der Tiefe oder der Reflexionszeit zu erhalten.

I — ABLEITUNG DER NÄHERUNGSFORMEL FÜR DIE ZEIT-ABSTANDSKURVE

1. Bezeichnungen.

Es seien

- v_v = Wellengeschwindigkeit in der v -ten Schicht
- γ_v = Neigung der v -ten Schichtgrenze gegen die Horizontale
- $\tau_n(x)$ = Laufzeit für den Strahl, der vom Schusspunkt $x = 0$ zum n -ten Reflexionshorizont und von dort zum Geophon x läuft
- α_{vn} = Einfallswinkel dieses Strahles an der v -ten Schichtgrenze auf dem Wege zum n -ten Horizont
- β_{vn} = der zu α_{vn} gehörige Brechungswinkel an der v -ten Schichtgrenze
- $\beta'_{vn}, \alpha'_{vn}$ = die entsprechenden Winkel nach der Reflektion
- $\omega_{vn}, \omega'_{vn}$ = Länge der Wege dieses Strahles in der v -ten Schicht

Mit einer Null als oberem Index werden die entsprechenden Stücke für den in sich reflektierten, also zum Schusspunkt zurückkehrenden Strahl versehen. Für diesen Strahl stimmen dann die einfachen und die gestrichenen Größen überein. Ferner ist $\beta^0_{nn} = \gamma_n - \gamma_{n-1}$.

$\tau_n(x)$ gibt die Laufzeitkurve für einen fest gewählten Schusspunkt. Wir müssen für unsere Zwecke die allgemeinere Funktion $\tau_n(u, x)$ betrachten, die als weitere Variable eine den Schusspunkt festlegende, senkrecht zum Streichen der Schichten variierende Koordinate enthält. $\tau_n(u, x)$ ist also die Laufzeit des Strahles, der vom Schusspunkt mit der Koordinate u über die Abstand x vom Schusspunkt, also zum Geophon mit der Koordinate $u + x$ läuft.

2. Angabe der Behauptung und Gedankengang des Beweises.

Die gesuchte Näherungsformel für die Laufzeitkurve ist nach den Ausführungen in der Einleitung bekannt, wenn $\tau''_n(0)$, genauer $\left(\frac{\partial^2}{\partial x^2} \tau_n(u, x)\right)_{x=0}$ ermittelt ist. Wir behaupten, dass

$$\left(\frac{\partial^2 \tau_n(u, x)}{\partial x^2}\right)_{x=0} = \frac{\cos^2(\alpha^0_{1n} + \gamma_1)}{K_n} \quad . \quad . \quad . \quad (7)$$

mit

$$K_n = 2 \sum_{v=1}^n \prod_{\mu=1}^{v-1} \frac{\cos^2 \alpha_{\mu n}^\circ}{\cos^2 \beta_{\mu n}^\circ} \omega_{vn}^\circ \nu_v$$

Aus (1), (5), (6) und (7) ergibt sich dann die Näherungsformel.

$$\begin{aligned} \tau_n(x)^2 = & \tau_n(0)^2 - \frac{2\tau_n(0) \sin(\alpha_{1n}^\circ + \gamma_1)}{\nu_1} x + \\ & + x^2 \left(\frac{\sin^2(\alpha_{1n}^\circ + \gamma_1)}{\nu_1^2} + \tau_n(0) \frac{\cos^2(\alpha_{1n}^\circ + \gamma_1)}{K_n} \right) \quad . \quad . \quad . \quad . \quad . \quad (8) \end{aligned}$$

wobei K_n die unter (7) angegebene Bedeutung hat. Als Spezialfälle seien der Fall paralleler Schichtgrenzen

$$\tau_n(x)^2 = \tau_n(0)^2 - \frac{2\tau_n(0) \sin \gamma_1}{\nu_1} x + x^2 \left(\frac{\sin^2 \gamma_1}{\nu_1^2} + \frac{\tau_n(0) \cos^2 \gamma_1}{2 \sum_{v=1}^n \nu_v D_v} \right) \quad (8_1)$$

(D_v = Mächtigkeit der v -ten Schicht), insbesondere der Fall horizontaler Schichten

$$\tau_n(x)^2 = \tau_n(0)^2 + \frac{\tau_n(0)}{2 \sum_{v=1}^n \nu_v D_v} x^2 \quad . \quad . \quad . \quad . \quad . \quad (8_2)$$

sowie der allgemeine Zweischichtfall

$$\begin{aligned} \tau_2(x)^2 = & \tau_2(0)^2 - \frac{2\tau_2(0) \sin(\alpha_{12}^\circ + \gamma_1)}{\nu_1} x + x^2 \left(\frac{\sin^2(\alpha_{12}^\circ + \gamma_1)}{\nu_1^2} + \right. \\ & \left. + \frac{\tau_2(0) \cos^2(\alpha_{12}^\circ + \gamma_1)}{2 \left\{ \nu_1 \omega_{12}^\circ + \nu_2 \omega_{22}^\circ \frac{\cos^2 \alpha_{12}^\circ}{\cos^2(\gamma_2 - \gamma_1)} \right\}} \right) \quad . \quad . \quad . \quad . \quad (8_3) \end{aligned}$$

aufgeführt.

Der Beweis für die Behauptung (7) wird durch Induktion über die Anzahl der Schichten geführt. Für $n = 1$ lässt sich die Behauptung durch Differentiation der bekannten Gleichung (2) sofort verifizieren. Einmalige Differentiation liefert

$$\tau_1(x) \frac{\partial \tau_1(x)}{\partial x} = \frac{1}{\nu_1^2} (x - \tau_1(0) \nu_1 \sin \gamma_1).$$

Nochmaliges Differenzieren ergibt

$$\tau_1(x) \frac{\partial^2 \tau_1(x)}{\partial x^2} + \left(\frac{\partial \tau_1(x)}{\partial x} \right)^2 = \frac{1}{\nu_1^2},$$

und unter Benutzung von (6) folgt das Ergebnis

$$\left(\frac{\partial^2 \tau_1(x)}{\partial x^2} \right)_0 = \frac{1}{\tau_1(0)} \left\{ \frac{1}{\nu_1^2} - \frac{\sin^2 \gamma_1}{\nu_1^2} \right\} = \frac{\cos^2 \gamma_1}{\nu_1^2 \tau_1(0)} = \frac{\cos^2 \gamma_1}{2 \nu_1 D_1},$$

das mit der Spezialisierung der Formel (7) auf den Fall $n = 1$ übereinstimmt. (7) ist also für $n = 1$ bewiesen.

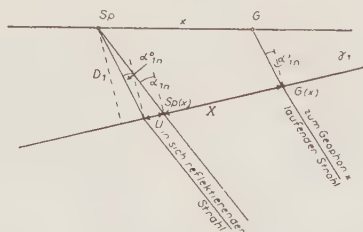


Abb. 1. Zur Ableitung der Näherungsformel.

Zum Beweis für beliebiges n wird nun die Gleichung (7) für $n-1$ als richtig angenommen und unter Benutzung dieser Induktionsvoraussetzung für n als richtig erkannt. Aus Abb. 1 liest man ab

$$\tau_n(x) = \frac{D_1}{v_1 \cos \alpha_{1n}} + \frac{D_1 - x \sin \gamma_1}{v_1 \cos \alpha'_{1n}} + \tau^{(n-1)}(x), \quad \dots \quad (9)$$

wobei $\tau^{(n-1)}$ die Zeit ist, die der Strahl in den $n-1$ unteren Schichten bleibt. Dabei ist $\tau^{(n-1)}$ eine Funktion von U und X , die ihrerseits wiederum Funktionen von x sind. Durch zweimalige Differentiation und Übergang zu $x = 0$ erhält man unter Benutzung der unmittelbar nachzuweisenden Beziehung

$$\left(\frac{d\alpha_{1n}}{dx} \right)_0 = - \left(\frac{d\alpha'_{1n}}{dx} \right)_0 \quad \dots \quad (10)$$

$$\begin{aligned} \left(\frac{\partial^2 \tau_n(x)}{\partial x^2} \right)_0 &= \frac{2 D_1}{v_1} \cdot \frac{1 + \sin^2 \alpha_{1n}^\circ}{\cos^3 \alpha_{1n}^\circ} \left(\frac{d\alpha_{1n}}{dx} \right)_0^2 + \frac{D_1}{v_1} \frac{\sin \alpha_{1n}^\circ}{\cos^2 \alpha_{1n}^\circ} \left\{ \left(\frac{d^2 \alpha_{1n}}{dx^2} \right)_0 + \frac{d^2 \alpha'_{1n}}{dx^2} \right\}_0 + \\ &+ \frac{2 \sin \gamma_1}{v_1} \frac{\sin \alpha_{1n}^\circ}{\cos^2 \alpha_{1n}^\circ} \left(\frac{d\alpha_{1n}}{dx} \right)_0 + \left(\frac{\partial^2 \tau^{(n-1)}}{\partial U^2} \right)_{x=0} \left(\frac{dU}{dx} \right)_0^2 + \\ &+ \left(\frac{\partial^2 \tau^{(n-1)}}{\partial U \partial X} \right)_{x=0} \left(\frac{dU}{dx} \right)_0 \left(\frac{dX}{dx} \right)_0 + \left(\frac{\partial \tau^{(n-1)}}{\partial U} \right)_{x=0} \left(\frac{d^2 U}{dx^2} \right)_0 + \\ &+ \left(\frac{\partial^2 \tau^{(n-1)}}{\partial X^2} \right)_{x=0} \left(\frac{dX}{dx} \right)_0^2 + \left(\frac{\partial^2 \tau^{(n-1)}}{\partial U \partial X} \right)_{x=0} \left(\frac{dU}{dx} \right)_0 \left(\frac{dX}{dx} \right)_0 + \\ &+ \left(\frac{\partial \tau^{(n-1)}}{\partial X} \right)_{x=0} \left(\frac{d^2 X}{dx^2} \right)_0 \quad \dots \quad (11) \end{aligned}$$

Der weitere Beweis besteht nun darin, die auf der rechten Seite von (11) auftretenden Ausdrücke zu berechnen und geeignet zusammenzufassen. Wesentlich ist dabei, dass die in (11) auftretenden zweiten Ableitungen der Einfallswinkel im weiteren Verlaufe der Umformungen herausfallen, dass man aber hinsichtlich der ersten Ableitungen der Winkel α_{1n} und α'_{1n} nicht mit der einfachen Beziehung (10) auskommt, sondern diese für den Grenzfall $x = 0$

selbst kennen muss und dass sie wiederum durch Induktion über n gewonnen werden können. Der Beweis wird also durch zweifache Induktion geführt.

3. Beweis der Beziehung (7).

Da nach Tüchel (1943) und mir (1953)

$$\left(\frac{\partial \tau^{(n-1)}}{\partial U}\right)_0 = -\frac{2 \sin \beta_{1n}^\circ}{v_2} \quad \left(\frac{\partial^2 \tau^{(n-1)}}{\partial U^2}\right)_0 = 0$$

$$\left(\frac{\partial^2 \tau^{(n-1)}}{\partial U \partial X}\right)_0 = 0$$

sowie nach Induktionsvoraussetzung

$$\left(\frac{\partial^2 \tau^{(n-1)}}{\partial X^2}\right)_{X=0} = \frac{\cos^2 \beta_{1n}^\circ}{K^{(n-1)}}$$

$$K^{(n-1)} = 2 \sum_{v=2}^n \omega_{vn}^\circ v_v \prod_{\mu=2}^{v-1} \frac{\cos^2 \alpha_{\mu n}^\circ}{\cos^2 \beta_{\mu n}^\circ}$$

ist, vereinfacht sich (11) zu

$$\begin{aligned} \left(\frac{\partial^2 \tau_n(x)}{\partial x^2}\right)_0 &= \frac{2 D_1}{v_1} \frac{1 + \sin^2 \alpha_{1n}^\circ}{\cos^3 \alpha_{1n}^\circ} \left(\frac{d \alpha_{1n}}{d x}\right)_0^2 + \frac{D_1}{v_1} \frac{\sin \alpha_{1n}^\circ}{\cos^2 \alpha_{1n}^\circ} \left\{ \left(\frac{d^2 \alpha_{1n}}{d x^2}\right)_0 + \left(\frac{d^2 \alpha'_{1n}}{d x^2}\right)_0 \right\} + \\ &+ \frac{2 \sin \gamma_1}{v_1} \frac{\sin \alpha_{1n}^\circ}{\cos^2 \alpha_{1n}^\circ} \left(\frac{d \alpha_{1n}}{d x}\right)_0 - \frac{\sin \beta_{1n}^\circ}{v_2} \left\{ 2 \left(\frac{d^2 U}{d x^2}\right)_0 + \left(\frac{d^2 X}{d x^2}\right)_0 \right\} + \\ &+ \frac{\cos^2 \beta_{1n}^\circ}{K^{(n-1)}} \left(\frac{d X}{d x}\right)_0^2 \dots \dots \dots (12) \end{aligned}$$

Nun ist

$$U = \text{const} + D_1 \text{tg } \alpha_{1n}; \quad X = x \cos \gamma_1 - D_1 (\text{tg } \alpha_{1n} - \text{tg } \alpha'_{1n}) - x \sin \gamma_1 \text{tg } \alpha'_{1n}$$

$$\begin{aligned} \text{daher} \quad \left(\frac{d^2 U}{d x^2}\right)_0 &= D_1 \left\{ \frac{2 \sin \alpha_{1n}^\circ}{\cos^3 \alpha_{1n}^\circ} \left(\frac{d \alpha_{1n}}{d x}\right)_0^2 + \frac{1}{\cos^2 \alpha_{1n}^\circ} \left(\frac{d^2 \alpha_{1n}}{d x^2}\right)_0 \right\} \\ \left(\frac{d X}{d x}\right)_0 &= \cos \gamma_1 - \sin \gamma_1 \text{tg } \alpha_{1n}^\circ - 2 D_1 \cdot \frac{1}{\cos^2 \alpha_{1n}^\circ} \left(\frac{d \alpha_{1n}}{d x}\right)_0 \\ \left(\frac{d^2 X}{d x^2}\right)_0 &= \frac{2 \sin \gamma_1}{\cos^2 \alpha_{1n}^\circ} \left(\frac{d \alpha_{1n}}{d x}\right)_0 - \frac{D_1}{\cos^2 \alpha_{1n}^\circ} \left\{ \left(\frac{d^2 \alpha_{1n}}{d x^2}\right)_0 - \left(\frac{d^2 \alpha'_{1n}}{d x^2}\right)_0 \right\} \quad (13) \end{aligned}$$

Wir fassen nun die Glieder zusammen in (12), die mit derselben Winkelableitung multipliziert sind. Mit $\left(\frac{d^2 \alpha_{1n}}{d x^2}\right)_0$ sind behaftet

$$\frac{D_1}{v_1} \frac{\sin \alpha_{1n}^\circ}{\cos^2 \alpha_{1n}^\circ}, \quad -\frac{2 \sin \beta_{1n}^\circ}{v_2} \cdot \frac{D_1}{\cos^2 \alpha_{1n}^\circ}, \quad \frac{\sin \beta_{1n}^\circ}{v_2} \cdot \frac{D_1}{\cos^2 \alpha_{1n}^\circ}.$$

Die Summe dieser Ausdrücke verschwindet. Dasselbe gilt für $\left(\frac{d^2 \alpha'_{1n}}{d x^2}\right)_0$, da

$$\frac{D_1 \sin \alpha_{1n}^\circ}{v_1 \cos^2 \alpha_{1n}^\circ} - \frac{\sin \beta_{1n}^\circ}{v_2} \cdot \frac{D_1}{\cos^2 \alpha_{1n}^\circ} = 0 \quad \text{ist.}$$

Die Summe der Koeffizienten von $\left(\frac{d\alpha_{1n}}{dx}\right)_0^2$ ist, wenn wir zunächst von dem letzten Gliede in (12) absehen,

$$\begin{aligned} \frac{2 D_1}{v_1} \cdot \frac{1 + \sin^2 \alpha_{1n}^\circ}{\cos^3 \alpha_{1n}^\circ} - \frac{\sin \beta_{1n}^\circ}{v_2} \frac{4 D_1 \sin \alpha_{1n}^\circ}{\cos^3 \alpha_{1n}^\circ} = \\ = \frac{2 D_1}{v_1 \cos \alpha_{1n}^\circ} = \frac{2 \omega_{1n}^\circ}{v_1}. \end{aligned}$$

Die mit $\left(\frac{d\alpha}{dx}\right)_0$ behafteten Glieder in (12), soweit sie nicht dem letzten Summanden angehören, heben sich wieder gegenseitig auf

$$\frac{2 \sin \gamma_1}{v_1} \frac{\sin \alpha_{1n}^\circ}{\cos^2 \alpha_{1n}^\circ} - \frac{2 \sin \gamma_1}{\cos^2 \alpha_{1n}^\circ} \frac{\sin \beta_{1n}^\circ}{v_2} = 0,$$

so dass von (12) nur übrigbleibt

$$\left(\frac{\partial^2 \tau_n(x)}{\partial x^2}\right)_0 = \frac{2 \omega_{1n}^\circ}{v_1} \left(\frac{d\alpha_{1n}}{dx}\right)_0^2 + \frac{\cos^2 \beta_{1n}^\circ}{K^{(n-1)}} \left\{ \frac{\cos(\alpha_{1n}^\circ + \gamma_1)}{\cos \alpha_{1n}^\circ} - \frac{2 D_1}{\cos^2 \alpha_{1n}^\circ} \left(\frac{d\alpha_{1n}}{dx}\right)_0 \right\}^2 \quad (14)$$

Wir werden sogleich zeigen, dass

$$\left(\frac{d\alpha_{1n}}{dx}\right)_0 = \frac{v_1 \cos(\alpha_{1n}^\circ + \gamma_1)}{K_n} \cdot \dots \dots \dots (15)$$

Mit Hilfe von (15) erhält man

$$\begin{aligned} \left(\frac{dX}{dx}\right)_0 &= \frac{\cos(\alpha_{1n}^\circ + \gamma_1)}{\cos \alpha_{1n}^\circ} - \frac{2 D_1}{\cos^2 \alpha_{1n}^\circ} \cdot \frac{v_1 \cos(\alpha_{1n}^\circ + \gamma_1)}{K_n} = \\ &= \frac{\cos(\alpha_{1n}^\circ + \gamma_1)}{\cos \alpha_{1n}^\circ} \left(1 - \frac{2 v_1 \omega_{1n}^\circ}{K_n}\right) = \\ &= \frac{\cos(\alpha_{1n}^\circ + \gamma_1)}{\cos \alpha_{1n}^\circ} \cdot \frac{\cos^2 \alpha_{1n}^\circ}{\cos^2 \beta_{1n}^\circ} \cdot \left(\frac{\partial^2 \tau_n(x)}{\partial x^2}\right)_0 \cdot \frac{K^{(n-1)}}{K_n} = \frac{2 \omega_{1n}^\circ}{v_1} \cdot \frac{v_1^2 \cos^2(\alpha_{1n}^\circ + \gamma_1)}{K_n^2} + \\ &+ \frac{\cos^2 \beta_{1n}^\circ}{K^{(n-1)}} \frac{K^{(n-1)^2} \cos^2 \alpha_{1n}^\circ \cos^2(\alpha_{1n}^\circ + \gamma_1)}{K_n^2 \cos^4 \beta_{1n}^\circ} = \\ &= \frac{\cos^2(\alpha_{1n}^\circ + \gamma_1)}{K_n^2} \left\{ 2 v_1 \omega_{1n}^\circ + \frac{\cos^2 \alpha_{1n}^\circ}{\cos^2 \beta_{1n}^\circ} K^{(n-1)} \right\} = \frac{\cos^2(\alpha_{1n}^\circ + \gamma_1)}{K_n}, \text{ q. e. d.} \end{aligned}$$

Die Gleichung (15) beweisen wir, wie schon erwähnt, durch Induktion. Da im Falle einer Schicht

$$x = \frac{\sin \alpha_{11}}{\cos \gamma_1} (\omega_{11} + \omega'_{11}),$$

so folgt $\cos \gamma_1 = \left(\frac{d\alpha_{11}}{dx}\right)_0 \cdot 2 D_1$, d.h. die Behauptung.

Aus der nach x differenzierten Snelliusschen Beziehung

$$\left(\frac{d\alpha_{1n}}{dx}\right)_0 = \frac{\cos\beta_{1n}^\circ}{\cos\alpha_{1n}^\circ} \cdot \frac{v_1}{v_2} \left(\frac{\partial\beta_{1n}}{\partial X}\right)_0 \left(\frac{dX}{dx}\right)_0$$

folgt mit Hilfe von (13) und der Induktionsvoraussetzung

$$\left(\frac{\partial\beta_{1n}^\circ}{\partial X}\right)_0 = \frac{v_2 \cos\beta_{1n}^\circ}{K^{(n-1)}}$$

die Gleichung

$$\left(\frac{d\alpha_{1n}}{dx}\right)_0 = \frac{v_1 \cos^2\beta_{1n}^\circ}{K^{(n-1)} \cos^2\alpha_{1n}^\circ} \cdot \left(\cos(\alpha_{1n}^\circ + \gamma_1) - 2\omega_{1n}^\circ \left(\frac{d\alpha_{1n}}{dx}\right)_0\right)$$

oder

$$(K_n - 2\omega_{1n}^\circ v_1) \left(\frac{d\alpha_{1n}}{dx}\right)_0 = v_1 \cos(\alpha_{1n}^\circ + \gamma_1) - 2v_1 \omega_{1n}^\circ \left(\frac{d\alpha_{1n}}{dx}\right)_0$$

aus welcher sich unmittelbar die gewünschte Beziehung ergibt. Damit ist die Behauptung und die angegebene Näherungsformel vollständig bewiesen.

4. Zur Genauigkeit der Näherungsformel.

In Anbetracht der sehr komplizierten Abhängigkeit der Laufzeitkurve von Lage und Mächtigkeit der Schichten und zugehörigen Geschwindigkeiten wollen wir keine allgemeine Untersuchung der bei Anwendung der Formel (8)

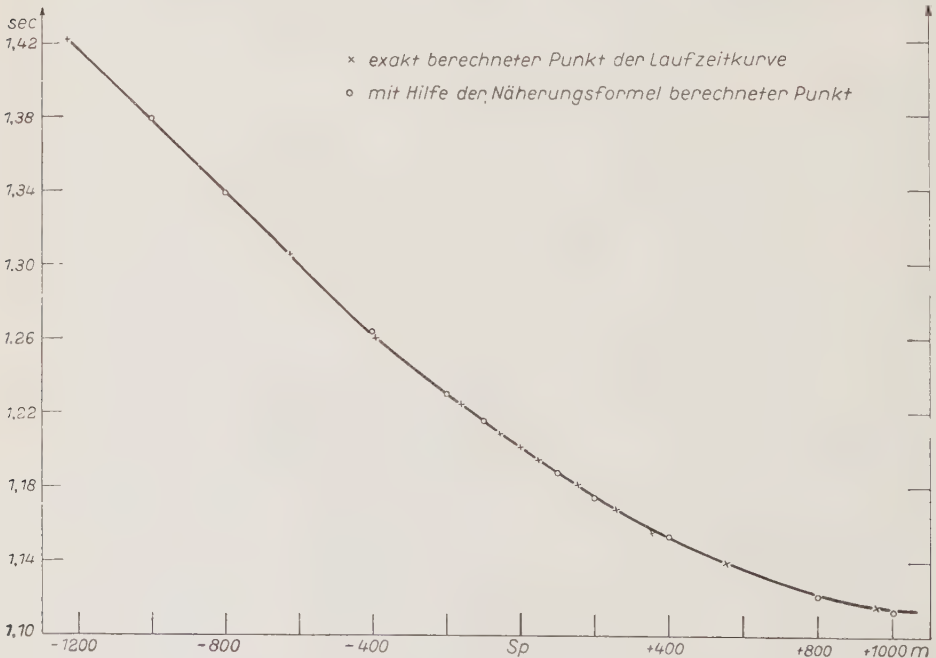


Abb. 2. Beispiel für eine Laufzeitkurve und die Genauigkeit der Annäherung durch Formel (8) $v_1 = 1800$ m/s, $v_2 = 3600$ m/s, $\gamma_1 = 0^\circ$, $\gamma_2 = 30^\circ$, $D_1 = 600$ m, $D_2 = 1000$ m

Tabelle 1

 $D_1 = 800 \text{ m}$, $v_1 = 2000 \text{ m/sec}$, $D_2 = 1000 \text{ m}$, $v_2 = 3000 \text{ m/sec}$

γ_0	x	T(x) gemessen	T(x) berechnet	T(O)	$\bar{u}$	v_m	Grösse d. Korrektur	
							absolut	in %
0	821.8	1.5028	1.5029	1.4667	2505	2454	+ 51	2.1 %
5	812.2	1.4669	1.4673	1.4667	2499	2454	+ 45	1.8 %
10	809.3	1.4315	1.4322	1.4667	2482	2454	+ 28	1.1 %
15	812.4	1.3960	1.3971	1.4667	2458	2454	+ 4	—
20	821.8	1.3601	1.3615	1.4667	2425	2454	— 29	1.1 %
25	837.9	1.3230	1.3248	1.4667	2386	2454	— 68	2.8 %
30	861.3	1.2842	1.2863	1.4667	2343	2454	—111	4.5 %
35	892.9	1.2428	1.2453	1.4667	2299	2454	—155	6.3 %
45	988	1.1481	1.1516	1.4667	2210	2454	—244	10 %

Tabelle 2

 $D_1 = 600 \text{ m}$, $v_1 = 1800 \text{ m/sec}$, $v_2 = 3300 \text{ m/sec}$, $\gamma = 25^\circ$

D_2	x	T(x) gemessen	T(x) berechnet	T(O)	$\bar{u}$	v_m	Grösse d. Korrektur	
							absolut	in %
300	420.1	0.7686	0.7693	0.8484	2115	2120	— 5	—
450	522.9	0.8400	0.8394	0.9374	2207	2235	— 28	1.3 %
600	625.6	0.9114	0.9136	1.0304	2274	2330	— 56	2.4 %
750	728.5	0.9828	0.9856	1.1212	2327	2410	— 83	3.5 %
1000	899.6	1.1018	1.1060	1.2727	2394	2510	—116	4.7 %
1200	1037	1.1969	1.2024	1.3940	2435	2580	—145	5.6 %

Tabelle 3

 $D_1 = 800 \text{ m}$, $v_1 = 200 \text{ m/sec}$, $D_2 = 800 \text{ m}$, $\gamma = 10^\circ$

v_2	x	T(x) gemessen	T(x) berechnet	T(O)	$\bar{u}$	v_m	Grösse d. Korrektur	
							absolut	in %
2500	628.1	1.4126	1.4126	1.4400	2228	2220	+ 8	—
3000	702.9	1.3028	1.3033	1.3333	2431	2400	+ 31	1.3 %
3500	780.1	1.2234	1.2246	1.2574	2615	2545	+ 70	2.8 %
4000	861.3	1.1630	1.1645	1.2	2786	2670	+116	4.3 %

Tabelle 4

 $D_1 = 600 \text{ m}$, $v_1 = 1800 \text{ m/sec}$, $\gamma_1 = 0^\circ$, $v_2 = 3600 \text{ m/sec}$, $\gamma_2 = 20^\circ$

Sp	No	W_{22}°	v_m	$\bar{u}$	Fehler in %
1	1500		2781	2971	6.8
2	1363.2		2737	2933	7.2
3	1226.4		2689	2889	7.4
4	1089.6		2635	2839	7.7
5	952.8		2574	2781	8.0
6	816.0		2505	2713	8.3
7	679.2		2426	2634	8.6
8	542.4		2335	2538	8.7
9	405.6		2226	2416	8.5

erreichten Genauigkeit in der Annäherung der $\tau(x)$ -Kurve geben. Wir beschränken uns darauf, die der Formel anhaftenden Fehler an einer grösseren Zahl verschiedenartiger Beispiele aufzuzeigen.

In den Tabellen 1, 2 und 3 ist eine Anzahl Beispiele mit zwei parallelen Reflexionshorizonten durchgerechnet worden. Es wird jeweils der Neigungswinkel, das Verhältnis der Schichtgeschwindigkeiten und das Verhältnis der Schichtmächtigkeiten variiert, während den anderen die Laufzeit mitbestimmenden Grössen feste Werte erteilt werden. Es ist dann stets für ein Geophon im Abstände x vom Schusspunkt die Laufzeit $\tau_2(x)$ berechnet worden; diese Zeit ist in Spalte 2 angegeben. Aus der dritten Spalte der Tabellen entnimmt man die Laufzeiten, die sich auf Grund unserer Näherungsformel ergeben. Man sieht, dass in fast allen Fällen die Unterschiede zwischen wahren und angenäherten Laufzeiten unterhalb der Messgenauigkeit liegen. Dabei ist der Abstand x stets so gewählt worden, dass die Länge der Aufstellung mit der Mächtigkeit der von den Wellen durchlaufenen Schichten etwa übereinstimmt.

Dasselbe Ergebnis erhält man aus dem in Abbildung 2 behandelten Beispiel, in welchem der erste Horizont als horizontal, der zweite um 30° geneigt angenommen wurde. Die wahre Laufzeitkurve ist mit Hilfe von 12 Werten gezeichnet worden; die aus Formel (8) gewonnenen angenäherten Laufzeitwerte für die Geophone im Abstand 100, 200, 400, 800, 1000 m fügen sich ohne grössere Unterschiede als 3 msec an den äussersten Geophonen in die Kurve ein.

Diese Beispiele zeigen nicht nur die Genauigkeit der Annäherung der $\tau(x)$ -Kurve durch die in (8) wiedergegebene Beziehung, sondern vor allem auch den hohen Grad von Berechtigung, im Rahmen der Reflexionsseismik unter Einschluss der reflexionsseismischen Langaufstellungen die Laufzeitkurven als Hyperbeln anzusehen.

5. Anwendung auf den Fall stetiger Änderung der seismischen Geschwindigkeit.

Die Gleichung (8₂), die angenähert die Laufzeitkurve in dem Falle wiedergibt, dass der Untergrund bis zum Reflexionshorizont aus n horizontal gelagerten Schichten konstanter Geschwindigkeit besteht, lässt sich leicht durch Grenzübergang $n \rightarrow \infty$ auf den Fall verallgemeinern, dass die Geschwindigkeit stückweise stetig von der Tiefe abhängt. Es ergibt sich für einen Reflexionshorizont in der Tiefe D

$$\tau_D^2(x) = \tau_D^2(0) + \frac{\tau_D(0)x^2}{2 \int_0^D v dD} \quad . \quad . \quad . \quad . \quad . \quad (16)$$

Hängt die Geschwindigkeit linear mit der Tiefe d zusammen so ist

$$v = v_0 + \alpha d,$$

so ist

$$\tau_D^2(x) = \tau_D^2(0) + \frac{\tau_D(0)x^2}{2v_0D + \alpha D^2} \quad . \quad . \quad . \quad . \quad . \quad (16_1)$$

Wenn

$$v = v_0 + \beta t,$$

d.h. v linear von der Reflexionszeit abhängt,

so ist

$$\begin{aligned} \tau_D^2(x) &= \tau_D^2(0) + \frac{\tau_D(0) x^2}{\frac{1}{2} \tau_D(0) \int_0^{\tau_D(0)} v^2 dt} \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad (16_2) \\ &\approx \tau_D^2(0) + \frac{x^2}{v_0^2 + \frac{v_0 \beta}{2} \tau_D(0)}. \end{aligned}$$

Besteht schliesslich ein parabolischer Zusammenhang

$$v^2 = v_0^2 + \delta t,$$

so folgt

$$\tau_D^2(x) = \tau_D^2(0) + \frac{x^2}{v_0^2 + \frac{\delta \tau_D(0)}{4}} \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad (16_3)$$

Zur Formel (16₁) wurde ein Beispiel durchgerechnet.

Es wurden $v_0 = 2000$ m/sec, $\alpha = 2$ sec⁻¹, $D = 500$ m, $x = 269.5$ gewählt. Es ergab sich ein Unterschied von 1/10 msec zwischen dem wahren und dem angenäherten Wert.

II. FOLGERUNGEN FÜR DIE BESTIMMUNG SEISMISCHER GESCHWINDIGKEITEN AUS REFLEXIONSEISMISCHEN MESSUNGEN

1. Verhalten der „Durchschnittsgeschwindigkeiten“.

In der Einleitung ist kurz skizziert worden, wie in der Praxis im allgemeinen reflexionsseismisch Geschwindigkeiten bestimmt werden. Unter Vernachlässigung der Brechung erhält man mit Hilfe der Beziehungen (3) oder (4) oder graphischer Verfahren eine Grösse $\bar{v}$, die man als Durchschnittsgeschwindigkeit verwendet. Da die Approximation der Laufzeitkurve durch eine Hyperbel in dem hier interessierenden Bereich um den Schusspunkt sehr genau ist, — was übrigens bedeutet, dass im Rahmen der Reflexionsseismik keine Abhängigkeit von dem zur Bestimmung benutzten Geophon besteht —, so ist mit ausreichender Genauigkeit das reziproke Quadrat von $\bar{v}$ gleich dem Koeffizienten von x^2 in dem Ausdruck (8), also

$$\frac{1}{\bar{v}^2} = \frac{\sin^2(\alpha_{1n}^\circ + \gamma_1)}{v_1^2} + \tau_n(0) \frac{\cos^2(\alpha_{1n}^\circ + \gamma_1)}{2 \sum_{v=1}^n \prod_{\mu=1}^{v-1} \frac{\cos^2 \alpha_{\mu n}^\circ}{\cos^2 \beta_{\mu n}^\circ} \omega_{vn} v_n}. \quad (17)$$

Im Falle paralleler Schichten mit einer gemeinsamen Neigung γ vereinfacht sich dieser Ausdruck erheblich:

$$\frac{1}{\bar{v}^2} = \frac{\sin^2 \gamma}{v_1^2} + \frac{\tau_n(0) \cos^2 \gamma}{2 \sum_{v=1}^n v_v D_v}, \quad \dots \quad (171)$$

wenn $D_v = \frac{v_v}{2} (\tau_v(0) - \tau_{v-1}(0))$ die Mächtigkeit der v -ten Schicht ist.

Wir wollen zunächst wieder den einfachen Fall zweier paralleler geneigter Schichten betrachten. In den Tabellen 1, 2 und 3 sind die funktionellen Zusammenhänge zwischen $\bar{v}$ und den Mächtigkeiten und Geschwindigkeiten der Schichten sowie der Neigung des Schichtpaketes deutlich gemacht. Diese Zusammenhänge sind in den Abbildungen 3, 4 und 5 graphisch wiedergegeben.

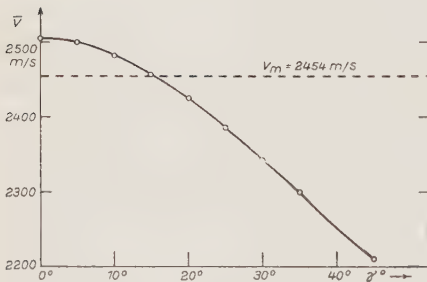


Abb. 3.

Abb. 3. Abhängigkeit von $\bar{v}$ von der Neigung der Schichten.

$v_1 = 2000$ m/s, $v_2 = 3000$ m/s, $D_1 = 800$ m, $D_2 = 1000$ m.

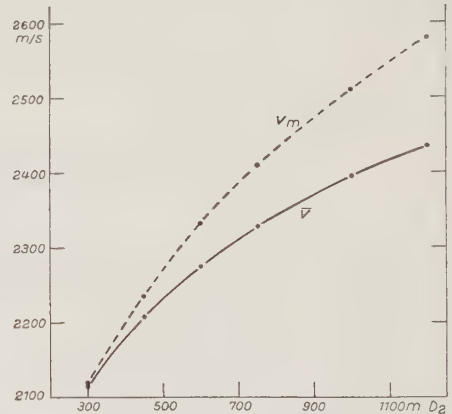


Abb. 4.

Abb. 4. Abhängigkeit von $\bar{v}$ von der Mächtigkeit der Schichten.

$v_1 = 1800$ m/s, $v_2 = 3300$ m/s, $D_1 = 600$ m, $\gamma = 25^\circ$.

Falls das Schichtpaket horizontal liegt, so ist $\bar{v}$ grösser oder gleich der wahren Durchschnittsgeschwindigkeit. Dieser Zusammenhang gilt aber nicht mehr, wenn die Schichten geneigt sind. $\bar{v}$ kann dann sogar beträchtlich kleiner sein als die Durchschnittsgeschwindigkeit. Die gerechneten Beispiele zeigen deutlich, dass ein genereller Abzug von etwa 2—3 % die Grösse $\bar{v}$ nicht immer in richtigem Sinne korrigiert.

In Tabelle 4 ist eine andere Abhängigkeit dargestellt. Unter einer horizontal gelagerten Schicht von 600 m Mächtigkeit mit einer Schichtgeschwindigkeit von 1800 m/sec befindet sich eine unter 20° geneigte Schicht mit einer Geschwindigkeit von 3600 m/sec, die unterhalb des ersten Schusspunktes eine Mächtigkeit von 1500 m hat. Wir bestimmen nun $\bar{v}$ für eine Folge von Schusspunkten, die jeweils einen Abstand von 400 m voneinander haben und in der Richtung senkrecht zum Streichen der ansteigenden Schicht aufeinander folgen. Man sieht,

dass die Werte für $\bar{v}$ jeweils beträchtlich zu gross sind. Als Neues ergibt sich, dass über die ganze Folge der neun Schusspunkte die Korrektur fast gleichbleibend von derselben Grösse ist.

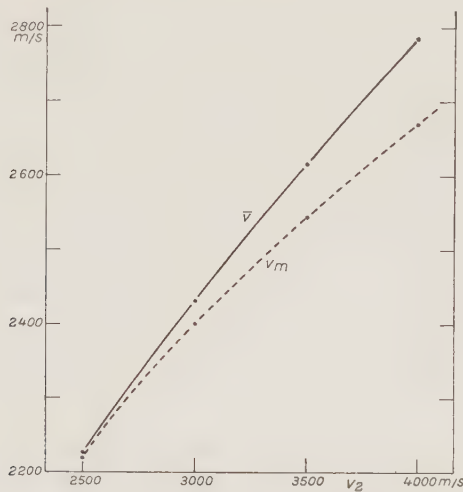


Abb. 5. Abhängigkeit von $\bar{v}$ von den Schichtgeschwindigkeiten.
 $v_1 = 2000$ m/s, $D_1 = 800$ m, $D_2 = 800$ m, $\gamma = 10^\circ$.

2. Korrektur der „Durchschnittsgeschwindigkeiten“, Formeln zur Berechnung von Schichtgeschwindigkeiten.

Zur Korrektur der $\bar{v}$ -Werte gibt es u.a. zwei Wege. Der erste Weg ist der, einen Korrekturfaktor f anzugeben, mit dem $\bar{v}$ multipliziert werden muss, um die wahre Durchschnittsgeschwindigkeit v_m zu erhalten, d.h. eine Funktion f anzugeben, die in Abhängigkeit von den Gegebenheiten angibt, um wieviel Prozent $\bar{v}$ verkleinert oder vergrössert werden muss. Im Falle zweier paralleler horizontaler Reflexionshorizonte gilt z.B.

$$f^2 = \frac{(1 + vt)^2}{(1 + t)(1 + v^2t)} \quad \text{mit } v = \frac{v_1}{v_2}, \quad t = \frac{\tau_1(O)}{\tau_2(O)},$$

bei vorhandener Neigung γ kommt noch ein Faktor

$$\left(1 + \frac{\sin^2 \gamma}{1 + t} \cdot \frac{1 - v^2}{v^2}\right) \quad \text{hinzu.}$$

Nun kann man den Einwand erheben, dass v_2 und damit v nicht bekannt sei. Man kennt aber, zumindest aus dem bekannten $\bar{v}$, schon einen ungefähren Wert für v_2 , und die Grösse des Korrekturfaktors wird von geringeren Fehlern in v_2 nicht sehr beeinflusst. Ausserdem kann man durch Iteration den Faktor f noch verbessern. So erhält man im letzten Beispiel der Tabelle 3 aus $\bar{v}$ statt 4000 für v_2 einen Wert von 4370 m/sec. Geht man mit diesem in die Formel

für den Korrekturfaktor ein, so bekommt man für v_m den schon gut angenäherten Wert 2635 m/sec. Bestimmt man hieraus für v_2 den zugehörigen Wert, setzt diesen wieder in den Korrekturfaktor ein, so bekommt man für v_m den Wert 2672 m/sec. In diesem Beispiel erreicht man also schon nach einfacher Iteration den genauen Wert für v_m . Dieses Verfahren ist insofern einigermaßen befriedigend, als 1., wie schon erwähnt, der Wert von v_2 f nicht zu stark beeinflusst, 2. die Konvergenz des Verfahrens ziemlich rasch ist, und 3. in der ungefähren Selbstreproduktion des angenommenen v_2 -Wertes ein einfaches Kriterium dafür vorliegt, ob die Korrektur schon hinreichend genau ist. Im allgemeinen Falle aber wird das entsprechende Verfahren zu kompliziert.

Bedeutend einfacher ist der Weg, zunächst mit Hilfe der Gleichung (17) oder im Falle paralleler Reflexionshorizonte mit Hilfe von (17₁) jeweils die Schichtgeschwindigkeiten zu bestimmen und dann entweder selbst zur Konstruktion zu verwenden oder zu Durchschnittsgeschwindigkeiten zusammenzusetzen. Dabei gehen im allgemeinen Falle (17) natürlich Lagerung und Geschwindigkeiten der oberen Schichten in die Rechnung ein, da die an den verschiedenen Horizonten in sich reflektierten Strahlen ganz verschiedenartige Wege zurücklegen.

Bei parallelen Schichten vereinfachen sich die Verhältnisse aber sehr, da der an der n -ten Schichtgrenze in sich reflektierte Strahl innerhalb der oberen $n-1$ Schichten auf demselben Wege verläuft wie der an der $(n-1)$ ten Schichtgrenze in sich reflektierte Strahl. Diese einfachen Verhältnisse machen es möglich, direkt aus den Werten für $\bar{v}_n$ und $\bar{v}_{n-1}$ die wahre Schichtgeschwindigkeit v_n der n -ten Schicht zu errechnen. Man erhält sofort

$$v_n^2 = \frac{\cos^2 \gamma}{\tau_n(0) - \tau_{n-1}(0)} \left\{ \frac{\tau_n(\sigma)}{I \frac{\sin^2 \gamma}{\bar{v}_n^2}} - \frac{\tau_{n-1}(0)}{I \frac{\sin^2 \gamma}{\bar{v}_{n-1}^2}} \right\}. \quad (18_1)$$

Dabei ist

$$\frac{\sin \gamma}{v_1} = \frac{\tau_n^2(x) - \tau_n^2(-x)}{4 \tau_n(0) x} \text{ und } \bar{v}_v^2 = \frac{2 x^2}{\tau_v^2(x) + \tau_v^2(-x) - 2 \tau_v^2(0)},$$

wobei x den Abstand der zur Geschwindigkeit benutzten, symmetrisch zum Schusspunkt gelegenen Geophone vom Schusspunkt ist.

Im Falle horizontaler Schichten vereinfacht sich dieser Ausdruck zu

$$v_n^2 = \frac{I}{\tau_n(0) - \tau_{n-1}(0)} \left\{ \tau_n(0) \bar{v}_n^2 - \tau_{n-1}(0) \bar{v}_{n-1}^2 \right\}^* \quad (18_2)$$

Diese Formel bleibt auf Grund der Überlegungen unter I,5 auch richtig, wenn die Geschwindigkeiten innerhalb der Schichten über den $(n-1)$ ten Reflexionshorizont nicht konstant sind, sondern irgendwelche stetigen Funktionen der Tiefe sind. Wenn man z.B. die Geschwindigkeit in einer Oberkreideschicht

* Diese Formel wurde von Prof. C. H. Dix in einem Vortrag auf der Tagung der Deutschen Geophysikalischen Gesellschaft im Oktober 1953 auf andere Weise abgeleitet.

unterhalb einer Tertiärschicht mit nicht konstanter Schichtgeschwindigkeit mit Hilfe von Formel (18₂) bestimmen will, so ist der zuletzt erwähnte Umstand kein Hindernis.

3. Bestimmung von Änderungen der Geschwindigkeit mit der Tiefe.

Zum Abschluss sei erwähnt, dass es mit Hilfe der Formeln (16₁) bis (16₃) bzw. weiterer aus (16) abzuleitender Gleichung möglich ist, mit einiger Sicherheit aus reflexionsseismischen Messungen den funktionellen Zusammenhang zwischen Geschwindigkeit und Tiefe zu bestimmen, falls man mehrere Reflexionen aus der Schicht erfassen kann, in der sich die Geschwindigkeit nach einem bestimmten Gesetz ändert. Ändert sich die Geschwindigkeit linear mit der Tiefe, so folgt aus (16₁) die Beziehung

$$\alpha = \frac{4}{\bar{v} \tau_D(0)} (\bar{v} - v_0). \quad . \quad . \quad . \quad . \quad . \quad (19_1)$$

Analog ergibt sich aus (16₂)

$$\beta = \frac{2(\bar{v}^2 - v_0^2)}{v_0 \tau_D(0)}, \quad . \quad . \quad . \quad . \quad . \quad (19_2)$$

schliesslich aus (16₃)

$$\delta = \frac{4(\bar{v}^2 - v_0^2)}{\tau_D(0)}. \quad . \quad . \quad . \quad . \quad . \quad (19_3)$$

Hat man z.B. Reflexionen aus sehr mächtigen Tertiärschichten, in welchen die Geschwindigkeit nur von der Tiefe abhängt, so kann man mit Hilfe von (19) oder ähnlicher Formeln feststellen, welches Gesetz diesen Zusammenhang am besten darstellt.

LITERATUR

- Dürbaum, H.: "Possibilities of constructing true ray paths in reflection seismic interpretation" (Geophysical Prospecting 1, 2).
 Krey, Th.: "An approximate correction method for refraction in reflection seismic prospecting" (Geophysics, July, 1951).
 Krousky, L.: "Eine Anwendung der regula falsi in der Reflexionsseismik", Erdöl und Kohle 5, 623 [1952].
 Tuchel, G.: "Seismische Messungen". Taschenbuch für angewandte Geophysik, Leipzig, 1943.

DISCUSSION

Mr. MATSCHINSKI: Sie sprechen in Ihren Ausführungen nur von Parallelschichten?

Mr. DÜRBAUM: Dieses Verfahren lässt sich ganz allgemein durchführen. Ich wollte nur der Einfachheit halber an einem Paket von Parallelschichten vor allem den durch die Neigung hervorgerufenen Effekt aufzeigen.

Mr. MATSCHINSKI: Aber es lässt sich doch allgemein durchführen?

Mr. DÜRBAUM: Ja, die Korrektur enthält dann die Winkel der in sich reflektierten Strahlen mit den einzelnen Schichten, und diese kann man ja leicht bestimmen.

Mr. MATSCHINSKI: Diese Methode setzt doch ebene Schichten voraus?

Mr. DÜRBAUM: Sie setzt voraus ebene Schichten in einem Bereich von etwa 500 m nach beiden Seiten.

Mr. MATSCHINSKI: Il me semble que, dans tous les cas, il est important de juger les hypothèses faites, de calculer les probabilités, ce que l'on peut faire par les méthodes que j'ai données dans mon précédent papier.

Mr. DIENESCH: Hatten Sie eine Gelegenheit eine Vergleichung zu machen zwischen den indirekten und den direkten Messungen in Bohrungen?

Mr. DÜRBAUM: Wir haben bisher einige Versuche gemacht, um solche Dinge zu vergleichen, hatten aber unglücklicherweise ein Beispiel genommen, wo wir zwar sehr gute Reflektionen hatten, aber keine Bohrlochversenkungsmessungen. Wo wir also nicht unmittelbar vergleichen konnten. Wir haben erst vor Kurzem mit der Auswertung von Seismogrammen, in einem Gebiet von Schleswig-Holstein wo wir Bohrungen haben, angefangen. Aber da kann ich noch keine Ergebnisse vorlegen. Bei dem oben genannten Beispiel haben sich jedenfalls auch mit der Formel mit 2. Ableitung für die oberen 3 Reflektionen, also auch für die Basis der Tertiär, der Unterkreide und der Oberkreide teilweise recht gute Resultate ergeben.

Mr. KREY: Zur Frage der Bestätigung der Brechungskorrekturen durch Geschwindigkeitsmessungen in Bohrlöchern, möchte ich auf eine briefliche Bemerkung hinweisen, die in Geophysics 1953 1 erschienen ist. Hierin wird von mir an einem Beispiel gezeigt, wie nach Anbringung der zur Debatte stehenden Korrekturen die Übereinstimmung zwischen Geschwindigkeiten nach der Methode der quadratischen Laufzeitkurve und denen nach Messungen in Bohrungen erheblich verbessert wird. Im übrigen begrüße ich es sehr, dass von Herrn Dürbaum jetzt auch das Problem der stärker geneigten Schichten behandelt wurde. Wenn ich Sie recht verstanden habe, so treten doch auch bei Ihnen schon bei der Entfernung $x = 0$ Unterschiede auf zwischen $\bar{v}$ und v_m .

Mr. DÜRBAUM: Ja, die Unterschiede zwischen $\bar{v}$, nach der Methode der quadratischen Laufzeitkurve bestimmt, und der wahren Durchschnittsgeschwindigkeit v_m sind schon bei Benutzung des Nullgeophons zur Bestimmung vorhanden.

Mr. KREY: Die Durchschnittsgeschwindigkeiten unterscheiden sich schon für $x = 0$. Das war das wesentliche Ergebnis meiner Arbeit, und das haben Sie auch also wiedergefunden.

Mr. DÜRBAUM: Ja, das ist eine ganz einfache Regel, man sollte 2 % abziehen, um die Brechung zu berücksichtigen. Es ist ja so, dass bei stärkeren Neigungen die Geschwindigkeit $\bar{v}$ durch die Brechung erheblich kleiner als v_m werden kann.

Mr. KREY: Das hat mich überrascht, das halte ich für neu und wertvoll, dass durch grössere Neigung das Vorzeichen eben auch anders werden kann.

Während bei horizontaler Neigung, ich habe da auch ein Beispiel durchgerechnet für grössere Entfernungen und bei exakter Berücksichtigung der Brechung, daran der Unterschied zwischen $\bar{v}$ und v_m immer grösser wird. Da braucht das also bei grösseren Neigungen nicht der Fall zu sein. Der Unterschied kann also wieder abnehmen, wie Sie das gezeigt haben.

E.A.E.G. ABSTRACT SERVICE

EXPLORATION — GENERAL

66. *Geophysical Crews busy in Record Numbers.*

World Oil, Vol. 136, No. 3, p. 100, Feb. 15, 1953.

Throughout the U.S.A. in 1952 there were 721 geophysical crews operating compared with 612 the previous year. Seismic crews numbered 638 against 530 in 1951; gravity, 81 against 76; and magnetic, 2 against 6. Texas was the most active state with 233 crews against 207 in 1951. Louisiana was next with 98 against 112. A table gives details of activity in each state.

67. *Geophysical Studies of the Bradanic Syncline* (In French).

Facca, Jaboli, Selem, & Roger, a paper read at the 19th International Geological Congress, at Algiers, Sept. 1952, (not yet published).

Over the Bradanic syncline the A.G.I.P. has conducted gravimetric, telluric, seismic-refraction, and reflection surveys. The results of all the work that has thrown light on the questions of regional geology are presented. The area is described as an interesting oil prospect.

68. *Three Geophysical Maps of the Aquitaine Basin, Southern Zone* (In French).

R.A.P., S.N.P.A., Richard & Beaufort, a paper read at the 19th International Geological Congress, at Algiers, Sept. 1952, (not yet published).

An outline of the major geological features of the Aquitaine basin is given, with a brief historical survey of the geophysical studies carried out in southern Aquitaine. Gravimetric, electric, and seismic analyses of the stratigraphy are given and the principle types of structure enumerated. The three maps, gravity, electric, and seismic, are compared to determine the advantages of each method. Application of these methods to a sedimentary basin is discussed.

69. *Exploration Societies look to Future.*

World Oil, Vol. 136, No. 5, pp. 76-80, April, 1953.

Accomplishments are reviewed, achievements recognized, and the new officers elected at the annual joint meeting of the AAPG, SEPM, and SEG, in Houston, Texas, are listed.

70. *Geophysical Activity reaches All-time High in 1952.*

E. A. Eckhardt, World Oil, Vol. 136, No. 5, pp. 82-87, April, 1953.

Oil & Gas J., Vol. 51, No. 47, pp. 144-147, March 30, 1953.

Throughout the world, 905 geophysical crews were operating during 1952. New reserves discovered totalled 3,300,000,000 brls. Consumption during the year was 2,550,000,000 brls.

71. *Australia is beating the bushes for oil.*

J. L. Marshall, World Oil, Vol. 136, No. 5, pp. 282-284, April, 1953.

The West Australia Petroleum Pty. Ltd. has commenced exploration of a 340,000 sq. ml. lease which extends along the northern coast and inwards almost to the eastern boundary of West Australia. Previous surface mapping and stratigraphic studies have established a total thickness of 11,000 ft. of Permian sediments in the Northwest Basin.

72. *Wildcat Score: 12,424 holes—2,334 wells.*

F. H. Lahee, *Oil & Gas J.*, Vol. 51, No. 47, pp. 138-143, March 30, 1953.

Report by the chairman of the A.A.P.G.'s Committee on Exploration Statistics, for 1952. Of 12,424 holes drilled, 2,334 were producers. A table gives the reasons for drilling each hole. Another table gives the results, and footage involved, of each hole.

73. *The Petroleum Geologist.*

M. J. Davis, *Oil & Gas J.*, Vol. 51, No. 47, pp. 165-168, March 30, 1953.

This paper discusses the contributions, activities, obligations, and future of the petroleum geologist.

74. *Our human Assets in Geophysics.*

C. H. Johnson, *Oil & Gas J.*, Vol. 51, No. 47, pp. 169-170, March 30, 1953.

A discussion of the human element in geophysics. The author predicts that geochemistry, which had a cold reception in 1940, will be regarded as an important oil-finding method by 1960.

SEISMIC — GENERAL

75. *The Need for Quantity and Quality in Velocity Surveys.*

L. Y. Faust, *Oil & Gas J.*, Vol. 51, No. 47, pp. 119-110, March 30, 1953.

A symposium was conducted under the auspices of the Geophysical Society of Tulsa. The purpose of the symposium was to raise questions concerning the optimum density of velocity surveys and the optimum precision of these surveys. It is shown that (1) the assumption of a constant velocity is erroneous. (2) A reasonably accurate representation is possible with a small amount of velocity control. (3) Large errors of prediction may eventually occur due either to miscorrelations or lack of adequate velocity control. (4) High precision surveys in sufficient quantity are necessary to resolve the causes of error.

76. *How to make Effective Use of Velocity-survey Data.*

B. G. Swan, *Oil & Gas J.*, Vol. 51, No. 47, pp. 120-122, March 30, 1953.

Facies changes may be detected through velocity maps and valuable deductions made concerning a basin's geologic history which can possibly be used in a more effective exploratory program. The author uses examples of lateral velocity gradients, time-depth curves, and regional velocity maps, to show how data may be used more effectively.

77. *How to improve Survey Accuracy.*

R. C. Kendall, *Oil & Gas J.*, Vol. 51, No. 47, pp. 124-126, March 30, 1953.

Several records are shown to illustrate the following points:

- (1) Various levels of amplification should be used, making sure that at least one is sufficiently low to see clearly the complete signal.
- (2) An attempt should be made to correlate the signals.

Ways of eliminating cable kick are described.

78. *How to improve Quality of First Breaks.*

N. R. Sparks, *Oil & Gas J.*, Vol. 51, No. 47, pp. 126-129, March 30, 1953.

To improve the quality of well-seismometer first breaks the amplification should be adjusted such that the wave form is clearly visible on the record for at least 0.1 sec. after the first break. This can be accomplished by using multi-trace recording at different gains, the lowest gain trace adjusted to meet this amplitude requirement.

79. *Time-measurement Problems.*

J. E. Owen, *Oil & Gas J.*, Vol. 51, No. 47, pp. 129-133, March 30, 1953.

Shot-hole fatigue causes time variations associated with the initiation of seismic impulse. Some practical examples are used to illustrate this, and remedies are suggested. Other problems are discussed.

80. *How much Control is needed?*

F. H. Cady, *Oil & Gas J.*, Vol. 51, No. 47, pp. 133-135, March 30, 1953.

In any particular area, the number of velocity surveys should be increased until the pattern of regional variations is established beyond doubt.

81. *Value of Velocity Surveys.*

P. L. Lyons, *Oil & Gas J.*, Vol. 51, No. 47, pp. 135-137, March 30, 1953.

A velocity survey identifies reflections, identifies over-all velocities, and defines interval velocities. In an area where several velocity surveys have been carried out, a new survey only serves to add another point to a velocity overlay. This does not necessarily warrant the cost of the survey. A practical example is given to illustrate the view that a good job may be done without any velocity surveys to assist.

82. *How Geology and Geography complicate Seismic Problems in Denver-Julesburg Basin.*

J. A. Kornfeld, *Oil & Gas J.*, Vol. 51, No. 47, pp. 152-160, March 30, 1953.

This discussion on the Denver-Julesburg Basin includes: Geological history, seismic history, field technique, record quality, interpretation problems, seismic velocities, regional velocity gradient, seismic corrections, and winter effects on seismic work.

SEISMIC — INSTRUMENTAL

83. *Seismic recording on Magnetic Tape.*

G. B. Loper & R. R. Pittman, a paper read at the 6th Annual Midwestern meeting of the S.E.G., at Fort Worth, Texas, Nov. 1952, (Not yet published).

A system of recording and reproducing exploration seismograms on magnetic tape is described. Each broad-band recording is formed into an endless loop and played back in repeating fashion. The signals are fed through a system of filters and mixers, then examined on a 12-trace cathode-ray oscilloscope. By varying the sweep speed of the oscilloscope, the entire record, or an expanded portion thereof, may be held stationary on the screen. Conventional paper records of the reproduced, modified record are finally made with a regular seismic camera.

84. *Cable Handling Device includes new features.*

J. E. Ortloff, *World Oil*, Vol. 136, No. 5, pp. 107-110, April, 1953.

Disadvantages of conventional cable reeling are: weight and expense of equipment; need for an operator whilst reeling; vulnerability of equipment. A new device is described which is simple in design, very light, requires no operator except truck driver, and is perfectly safe in operation. It is manufactured as a unit which may easily be fitted to any cable truck, in a very short time. The development of the device and some of its adaptations are described.

SEISMIC — FIELD TECHNIQUE

85. *Seismic Techniques in West Texas.*

P. C. Ingalls, *Oil & Gas J.*, Vol. 51, No. 40, p. 169, Feb. 9, 1953.

Conventional seismic methods over the Edwards Plateau of West Texas do not yield satisfactory results. Air shooting showed a little improvement but was not satisfactory.

The present trend is multiple shooting. Up to 36 shot holes are grouped in a circle 250 to 300 ft. across. Holes are about 50 ft. deep and the charges used are about 10 lb. per hole. Up to 40 geophones are set in patterns over areas up to 200 ft. by 500 ft. with about 12 patterns to a spread. This method often produces usable records in areas where previously none were obtained.

86. *New Aerial Shooting Technique Faster.*

J. J. Jakosky, *Petroleum Engineer*, Vol. 25, No. 2, pp. B. 85-88, Feb., 1953.

The new air shooting technique, in which a mortar projects a high-velocity explosive bomb to any pre-determined height between 50 and 600 ft., eliminates the need for expensive drilling equipment, shooting trucks, and water trucks. Output is increased and cost is lowered.

87. *A Seismic Velocity Logging Method.*

C. B. Vogel, *Geophysics*, Vol. 17, No. 3, pp. 586-597, July, 1952.

A well logging method is described which measures seismic velocity as a function of depth. The method uses a transient sound pulse, thus making possible the resolution of shear waves. Various systems of sources and receivers for minimizing borehole errors are discussed. With the most elaborate system considerable accuracy is obtainable in the face of large borehole diameter variations.

SEISMIC — INTERPRETATION

88. *Interpretation Method for Well Velocity Surveys.*

D. Walling & C. H. Savit, a paper read at the 6th Annual Midwestern meeting of the S.E.G., at Fort Worth, Texas, Nov. 1952, (not yet published).

Well surveys often suffer from the problem of "cable lead" and other extraneous energy arrivals. All the energy arrivals at the well seismometer may be individually timed by the use of phase differences occurring in differing amplifier filters. Special shot-hole patterns and a simple graph enable the interpreter correctly to identify all energy paths. No new equipment or instrumentation is needed. Laboratory tests and an actual survey illustrate the method.

89. *Better Seismic Reflection Records.*

R. B. Rice, *World Oil*, Vol. 134, No. 5, pp. 120-127, April, 1952.

If more consideration were to be given to the following five factors, there would be an improvement in the interpretation of seismic records. The author deals in detail with each of these factors:

1. Picking arrival times of reflections.
2. Computing time corrections.
3. Using velocity curves.
4. Computing cross-sections and maps.
5. Reflections and background noise.

90. *Wavefront Charts and Raypath Plotter.*

A. W. Musgrave, *Quart. Colorado Sch. Mines*, Vol. 47, No. 4, October, 1952.

This paper is concerned principally with the mathematical developments leading to the making of wavefront charts for the assumption of the linear increase of velocity with vertical time, and the construction of an electro-mechanical device for computing and drawing the curves. The author believes that the linear-with-time velocity assumption fits more field data than any other. Since there is no available device which can plot the path of the seismic energy satisfying this relationship, the necessity arose to design an instrument which would either plot directly or which

would enable a chart to be prepared for facilitating the work. It was decided to make a raypath plotter which would produce commercially accurate charts. The plotter was constructed by the Colorado School of Mines Research Foundation, Incorporated, who now operate it and distribute the charts for the benefit of the entire geophysical industry.

SEISMIC — THEORY & RESEARCH

91. *Velocity Measurements in Near-Surface Formations.*

J. E. White & R. L. Sengbush, *Geophysics*, Vol. 18, No. 1, pp. 54-69, Jan. 1953.

Procedures are described for measuring various seismic velocities at shallow depths in the earth, and examples of resulting logs are presented. Velocities in Austin chalk and Eagle Ford shale show that these formations are not isotropic, and velocities in loose sand are seen to increase smoothly with depth for an abrupt increase in compressional speed at the water table. Elastic constants for chalk and shale are computed. A discussion is given of the literature dealing with a packing of spheres as a model for loose sand, and an approximate theory is presented which includes tangential forces between spheres.

92. *The Origins and Nature of Microseisms in the Frequency Range 4 to 100 c/s.*

C. D. V. Wilson, *Proc. Roy. Soc. A.*, Vol. 217, No. 1129, pp. 176-188, 8 April, 1953.

Microseisms in the frequency band 4 to 100 c/s, commonly encountered in seismic prospecting, have been investigated in various parts of England, urban and rural. A diurnal variation in background level, indicating man-made sources, was found everywhere within two miles of a major road or community. The main sources were found to be traffic, heavy machinery, aircraft, wind and rain, with traffic prevailing. In rural areas at night-time a steady background of about 10^{-6} cm/s r.m.s. particle velocity was found, with occasional superimposed activity lasting 4 to 30 s. The latter has been shown to be mostly local and of geophysical origin, the precise nature of which is unknown. Various possible causes are discussed, both of this and of the minimum background.

93. *An Analysis of the Vibrations emitted by some Man-made Sources of Microseisms.*

C. D. V. Wilson, *Proc. Roy. Soc. A.*, Vol. 217, No. 1129, pp. 176-188, 8 April, 1953.

Study of the vibrations from traffic and machinery shows that most of the man-made microseisms are in the 4 to 10 c/s range, at least near Cambridge. Examination of traffic microseisms shows that surface waves predominate at 200 yards or more from the source. Their frequency depends more on geological conditions than separation of source and observer. Microseisms from a waterworks pump were recorded up to 4 miles away, and consisted of bodily waves of 15 to 42 c/s frequency, and surface waves of 7 to 10 c/s which predominated at distances greater than $\frac{1}{2}$ mile from the pump.

It is concluded that the bulk of microseisms are surface waves from traffic and machinery, but their attenuation renders them insignificant in most cases at a distance of 2 miles.

GRAVITY — GENERAL

94. *Comparison of the Acceleration due to Gravity at the National Physical Laboratory, Teddington, the Bureau International des Poids et Mesures, Sèvres, the Physikalisch-Technische Bundesanstalt, Brunswick, and the Geodetic Institute, Potsdam.*

A. H. Cook, *Proc. Roy. Soc.*, Vol. 213, No. 1114, pp. 408-424, July 8, 1952.

The values of gravity at these stations have been compared by means of pendulum

observations with Invar invariable pendulums. The observed differences of gravity from the N.P.L. are.

B.I.P.M.	-256.73 ± 0.49 mgal.
P.T.B.	$+68.68 \pm 0.49$ mgal.
Bad Harzburg	-15.68 ± 0.49 mgal.

The accuracy of the measurements is not so great as has been achieved once or twice previously with the same apparatus, mainly because the changes in the lengths of the pendulums were greater than usual.

These differences have been combined with German pendulum observations and with gravimeter comparisons with the following results.

Value of gravity at N.P.L. on the Potsdam system: 981196.29 ± 0.3 mgal.

Differences between sites of absolute determinations of gravity:

N.P.L. — B.I.P.M.	$+256.45 \pm 0.3$ mgal.
N.P.L. — P.T.B.	-68.98 ± 0.3 mgal.
P.T.B. — Potsdam	-8.95 ± 0.4 mgal.
("g" at Potsdam = 981274 mgal)	

The effects of these results on gravity surveys based on Cambridge and on the absolute value of gravity are indicated.

95. *Gravity Observations in a Borehole.*

R. L. G. Gilbert, *Nature*, Vol. 170, No. 4323, pp. 421-425, Sept. 6, 1952.

A vibrating string gravimeter was used to measure the variation of gravity in a borehole in the Eakring oilfield at depths between 178 ft. and 1,226 ft. The probable error of a single observation is about 0.7 mgal. The densities of the rocks penetrated have been calculated from the variation of gravity and agree well with values found from laboratory measurements on chippings from the drilling of the borehole.

96. *Gravity and Magnetometer Surveys for Chromite Ore Deposits in Turkey.*

K. Ergin, a paper read at the 19th International Geological Congress at Algiers, Algeria, September, 1952. (Not yet published).

During the Summer of 1951 a joint gravity and magnetometer survey was undertaken. Positive vertical anomalies of the order of 2,000 gammas or more were encountered over chromite outcrops. A vertical magnetometer survey obtained several magnetic anomalies over this area. Results of the surveys are discussed.

97. *An Interpretation of the Gravity Anomalies in the Eastern Mediterranean.*

J. C. Harrison & R. W. Hey, a paper read at the 19th International Geological Congress at Algiers, Algeria, September, 1952. (Not yet published).

The results of the 1950 British submarine gravity survey are interpreted together with the relevant measurements of other observers.

98. *The Extension into the Sahara of the North African Gravity Network.* (In French).

J. Lagrula, a paper read at the 19th International Geological Congress at Algiers, Algeria, September, 1952. (Not yet published).

A summary is given of North African gravity work. A map showing the isostatic anomalies is given (anomalies are computed on the basis of the Airy hypothesis with the depth of compensation at 60 km.). The difficulties arising in the calculation of precise isostatic anomalies in the Sahara are described. Provisional anomalies and their precision are given.

GRAVITY — THEORY & RESEARCH

99. *On the Problem of the Gravimetric Influence of Structures given by Depth Contours. Application to Topographic Corrections.*

V. Baranov, *Geophysical Prospecting*, Vol. 1, No. 1, pp. 36-43, March, 1953.

The triple integral for the attraction of a mass on a point is transformed in a double sum. This double sum serves to construct a graph for the rapid determination of the gravimetric influence of structures given by depth contours. The influence of topography can also be computed with this graph.

100. *The Free-Air Reduction of Gravity to the Second Order.*

H. Jeffreys, *Mon. Not. Roy. Astronom. Soc., Geophys. Suppl.* Vol. 6, No. 5, May, 1952.

A definition of height is given in terms of the geopotential that will agree to the second order with the height determined by direct measurement along the vertical where such measurement is possible. The free-air reduction of gravity is carried to the second order so as to permit allowance for terms in 'eh' and 'h²'

MAGNETIC — GENERAL

101. *Magnetic Properties of Rocks.*

Nature, Vol. 171, No. 4351, pp. 500-502, March 21, 1953.

A discussion on the significance of the natural remanent magnetism of igneous and sedimentary rocks.

102. *Gravity and Magnetometer Surveys for Chromite Ore Deposits in Turkey.*

K. Ergin, a paper read at the 19th International Geological Congress at Algiers, Algeria, September, 1952. (Not yet published).

During the summer of 1951 a joint gravity and magnetometer survey was undertaken. Positive vertical anomalies of the order of 2,000 gammas or more were encountered over chromite outcrops. A vertical magnetometer survey obtained several anomalies over this area. Results of the surveys are discussed.

MAGNETIC — INSTRUMENTAL

103. *Patents.* Abstracts in Geophysics, Vol. 18, No. 1, p. 225, January, 1953.

U.S. 2,603,687. 15th July, 1952. An electron-beam magnetometer.

U.S. 2,605,072. 29th July, 1952. A Self-orienting Total-field Magnetometer.

U.S. 2,610,226. 9th September, 1952. Aeromagnetic Survey System.

U.S. 2,611,802. 23rd September, 1952. Aeromagnetic Survey Recording System.

U.S. 2,611,803. 23rd September, 1952. Aeromagnetic Survey Recording System.

104. *An Apparatus for recording Small Changes in the Earth's Magnetic Field.* (In French).

H. Dürschner, *Ann. Geophys.*, Vol. 7, No. 4, pp. 199-207, 1951.

A magnetometer magnet is placed between two Helmholtz coils providing a compensating field, and the reflection from a mirror fixed to the magnet is recorded by means of two photo-electric cells on a milliammeter. Details of the apparatus are given, its sensitivity is discussed, and results of some measurements are shown.

MAGNETIC — FIELD TECHNIQUE

105. *Patents.* Abstracts in Geophysics, Vol. 17, No. 4, p. 952, October, 1952.

U.S. 2,598,697. 3rd June, 1952. Aeromagnetic Surveying Method.

U.S. 2,598,698. 3rd June, 1952. Aeromagnetic Surveying Method.

MAGNETIC — INTERPRETATION

106. *Principle of Direct Interpretation Methods in Gravimetry and Magnetism.*

B. Farre & R. Dalby, *Rev. Inst. Franc. Petr.*, Vol. 7, No. 7, pp. 217-234, 1952.

The indirect classical methods for interpreting the potential field observed at the surface of the earth usually involve the assumption of a mass distribution for which the effects are calculated, and this distribution is progressively modified until a close fit with the observations is obtained. In the indirect method discussed the observed field is continued downwards by analytical means so as to approach the actual structure, and this involves the calculation of the successive derivatives of the vertical component of the field. The mathematical basis of the method is indicated, and diagrams illustrate the comparative closeness with which the second derivatives reveal the geological features when the anomalies are well defined.

107. *A Review of Magnetic Interpretation Techniques.*

J. Affleck, a paper read at the Eastern Canada meeting of the S.E.G., at Toronto, Ontario, October, 1952. (Not yet published).

A review of the established methods of interpreting magnetic surveys. The advantages and limitations of the magnetic method are described. While the emphasis is on exploration for petroleum, the utilization of the technique in the search for metallic minerals is discussed.

ELECTRICAL

108. *Ore Body Size Determination in Electrical Prospecting.*

H. O. Seigel, *Geophysics*, Vol. 17, No. 4, pp. 907-914, October, 1952.

A method of determination of the size of an ore body associated with a mineralized intersection is presented which utilizes the primary voltage disturbance created by the body and the variation of the disturbance with electrode spacing. The form of the disturbance function is compared with theoretical curves based on the oblate spheroid.

109. *Surface Electrical Method detects Oil directly.*

H. M. Evjen, *World Oil*, Vol. 136, No. 2, pp. 93-96, February 1st, 1953.

An electromagnetic method which indicates the presence of oil by measuring the resistivity of subsurface formations from the surface of the ground. Low frequencies, 0 to 10 cycles/sec. are necessary to gain the required penetration. Thus the depth to be explored is about one quarter of the wavelength used. At these low frequencies, the speed of the wave is comparable to the speed of seismic waves. Examples of the practical use of this method are discussed.

110. *Apparent Resistivity Curves for Dipping Beds.*

M. Unz, *Geophysics*, Vol. 18, No. 1, pp. 116-137, January, 1953.

The apparent resistivity calculations published for the two layer case with an inclined interface can be applied to small dip angles only. They are also limited to small ratios of the electrode spacing in relation to depth. This investigation covers the complete range of dip angles and electrode spacings.

The theory of reflected images is not generally applicable to the case of dipping layers, as assumed until now. Only for certain particular values of the dip do the methods of this theory remain in force. For all other dip angles practically sufficient results are obtainable by interpolation. The calculations are exact in cases with a bottom layer of very high or negligibly low resistivity. For the intermediate resistivity values an approximation method is available.

Simple algebraical expressions are obtained for the apparent resistivity curves. An approach to multilayer problems is discussed. The field procedure is outlined.

- III. *Patents*. Abstracts in Geophysics, Vol. 18, No. 1, p. 225, January, 1953.
U.S. 2,608,602. 26th August, 1952. Electrical Detecting System for Prospecting or Well Logging.
U.S. 2,611,004. 16th September, 1952. Electrical Prospecting System.

WHAT IS OUR CONTRIBUTION? *

BY

D. T. GERMAIN-JONES **

Some years ago a policeman who was charging me with a minor motoring offence described me in the summons as a commercial traveller. He had not come across a geophysicist before, and he was afraid that in court he would be unable to pronounce the word and, worse still, he would be stricken dumb if the judge were to ask him what it meant. When the time came for me to appear before the court I raised an objection to my new appellation, and thereby caused much discomfiture to the policeman.

The above incident came into my mind as I was about to embark on the onerous task of preparing this address, and it set me thinking. A commercial traveller seeks to sell his wares and to advertise their virtues: why should I not follow his lead and try to do the same for geophysics? Our profession has much to offer, but when it comes to advertising that fact we are either unduly modest or downright lazy; or if you prefer it, we are all far too busy to do anything about it. The profession suffers in consequence, and the public remains in blissful ignorance of the considerable contribution which we make towards the maintenance of its modern standard of living. Today, therefore, I have no hesitation in assuming the role of a commercial traveller.

Until the advent of the Third World Petroleum Congress in 1951 our knowledge of the geophysical activity in Europe, outside our own particular countries, was decidedly meagre, though we all knew something about the immense effort in North America because it was widely publicised and because it had valuable representation in an admirable organisation, The Society of Exploration Geophysicists. Fortunately for us, the problem of bringing together the geophysicists in Europe, coordinating their work and shedding light on their efforts, was receiving the attention of a small band of thoughtful geophysicists, and their activity resulted in the birth of our Association in December, 1951. The response was remarkable. Our founder membership exceeded 300, and within two years the membership had more than doubled, with applications still pouring in. This meeting in Copenhagen is our sixth, others having

* Presidential Address delivered at the Third Annual Meeting of European Association of Exploration Geophysicists, held in Copenhagen on 19th/22nd May, 1954.

** Anglo-Iranian Oil Company, Limited, London.

been held in The Hague, London, Hanover, Paris and Milan. Travelling in Europe today is expensive and not always easy but, despite such factors, the attendances at our meetings are extraordinarily good. At our fourth meeting (in Paris) we had an attendance of approximately 180, and members came from all over Western Europe.

So far, there has been no dearth of technical material for presentation at these meetings: it has, in fact, been difficult at times to accommodate all the papers in the three days allocated. The standard of the papers has been high, and we may take pride in the fact that a paper presented at our London meeting won the Best Paper Award of the Society of Exploration Geophysicists. A notable feature of the material presented has been the wide range of topics covered in the field of geophysical prospecting, and the material itself affords ample proof of the high quality and of the enthusiasm of European geophysicists.

Just over a year after the formation of the E.A.E.G. we launched our journal 'Geophysical Prospecting'. It was a daring step to take in a number of ways, but in all respects it has been a great success. We now have a medium through which we can keep each other informed of our work and enable the world to learn something of our efforts. Needless to say, it must always be our endeavour to keep the standard of our publications in the journal high. While on the topic of the journal I would like to take the opportunity of expressing our appreciation of the support we have received from our advertisers. We are glad of the financial benefit we derive from their advertisements, but we value also the implied confidence by industry in the future of our profession.

It is clear from this evidence that the geophysical effort in Europe is considerable, and that it is characterised by a marked enthusiasm. The actual magnitude of this effort has been a subject of some interest to me during the past year or so, and I have endeavoured to secure some statistics by addressing enquiries to various organisations in the different countries, excluding those in the East. One day, I hope, one of our colleagues from over the border will be able to supplement our figures for the West. Altogether, I posted well over one hundred questionnaires, and I received replies to almost every one. Not all the replies were of use for my purpose because I discovered that many of the recipients were not actually engaged in geophysical prospecting, though their interests were not entirely divorced from it. However, I was able to make practical use of well over sixty of them, though I must make it quite clear that I have by no means exhausted all possible sources of information. That is a job which takes a great deal of time, and I have not been able to devote that time to it. Nevertheless, the results of this limited enquiry are of considerable interest, and I propose to give you some of the highlights. Though given in the present tense, it must be borne in mind that all figures refer to the latter half of 1953.

PERSONNEL

It appears that there are at least 710 geophysicists employed by organisations in Western Europe on work directly concerned with geophysical prospecting, two-thirds of that number being associated with geophysical contracting companies. These men are supported by approximately 1100 technical personnel such as observers, computers and technical assistants. In addition, there are hundreds of men employed on instrumental development, manufacture and maintenance, and also on administrative work. For example, one large contracting company which has nearly 50 parties of various kinds employs well over 500 technical people in addition to its staff of approximately 150 geophysicists. There are other contracting companies with about 20 parties who employ approximately 100 technical staff in addition to nearly 50 geophysicists.

The distribution of the geophysicists is as follows:

<i>France</i>	<i>Germany</i>	<i>England</i>	<i>Holland</i>	<i>Italy</i>	<i>Other countries</i>
35 %	21 %	19 %	14 %	6 %	5 %

There are also many geophysicists attached to various academic institutions who are not concerned with prospecting, but the results of their work can sometimes be of great value in the prospecting sphere. It is gratifying to note that a number of such men are members of this association, and they play no mean part in maintaining the high standard of our technical meetings.

The availability of qualified personnel varies in the different countries. For example, there appears to be little difficulty in recruiting suitable men in France, whereas in Germany it is not so easy. Difficulty is experienced in Britain, though the position there seems to be improving. There is difficulty also in Sweden, where mining geophysics is of prime importance. In my opinion, the blame for shortage of suitable men can be laid at the door of the profession itself. It is too tightly wrapped in its own cocoon, and it is time it emerged into the sunlight. You and I know perfectly well what a full and interesting life this profession has to offer; how exciting and how rewarding the work can be. And because of this I cannot believe that numerous young men could resist its appeal if they only knew about it. During the past year I have interviewed a considerable number of graduates applying for posts as geophysicists and in almost all cases the candidates had little or no idea of the nature of the work involved: and this is thirty years after the profession first became established. I think most of us would agree that the majority of the first class men in other professions today had already formulated their ideas on the nature of the work they wished to take up long before they completed their university training, and they made their preparations accordingly. How can we expect to divert some of the cream into our own channels if we do not publicise our profession as one which is worthy of consideration? We should talk about it, write about it and describe it in popular lectures. Put it over to the universities, the technical institutions and, above all, to the boys who are about to leave school. A job such as ours will rouse the interest of any normal

schoolboy, and from those who proceed to the university you will thereby be guaranteed a flow of well-trained recruits who will safeguard the future. Geophysics is not a passing phase, and we must adopt a long term view. One large oil company on this continent learned the lesson years ago, and it deserves high praise for its lavish expenditure on subsidising the geophysical departments of universities and in awarding studentships and scholarships in geophysics. It is an example on which others might well ponder.

FIELD ACTIVITY

Almost every company in Western Europe interested in geophysical exploration employs contract parties, including those companies who have parties of their own. A few of the contract parties on oil surveys come from the U.S.A., but there are about 170 provided by the 10-12 contractors, large and small, established on this side of the Atlantic. This number includes all types of parties, a few of them being employed on special problems of industrial interest such as foundation investigations, fault problems in coalfields and water-finding. In addition, there are over 60 parties which are company owned, making a total in excess of 230. These are made up as follows:

<i>Seismic</i>	<i>Gravity</i>	<i>Magnetic</i>	<i>Electrical/Tellural</i>
117	42	19	55
(50 %)	(18 %)	(8 %)	(24 %)

It is interesting to learn that just under 60 % of the contract parties are supplied by France and Germany, and nearly 20 % by Great Britain.

Not included in the above figures are some parties engaged on special projects by scientific institutions. These are concerned with investigations in pure seismology and of the earth's gravitational and magnetic fields, with investigations in polar regions, with special problems in geology, and so on.

The advantages which the airborne magnetometer has to offer in certain instances have not been overlooked by exploration companies on this side of the Atlantic, and last year over 120,000 square miles of territory were examined with this instrument operated by a British contractor.

It was not my intention to deal with well-logging parties but, in passing, it may interest you to know that one well-known contractor had nearly 40 of these parties employed last year.

I need hardly remark that the emphasis has been on seismic reflection work, and I sometimes wonder if we follow too closely the tendencies of our American colleagues in this respect. Too many geophysicists these days appear to have the idea that the seismic refraction technique is obsolete, and that reflection will furnish all the answers that refraction can give, and more. Experience has taught me that this can be far from the truth. It depends, of course, on the nature of the problem, but I remember important instances in oil exploration where refraction has given the answer where reflection would

not; and others where refraction has given the information, with all the precision necessary for preliminary well location purposes, in a far shorter time than reflection could ever have done. Much too frequently is there the tendency to spend valuable time and money on attempts to produce workable reflections without even considering the possibilities of refraction. In virgin areas where there is reason to suspect the existence of large scale structures of considerable amplitude it is, to my mind, folly not to examine the possibilities of long-range refraction arc and line observations before contemplating the use of reflection. Unfortunately, few seismic parties exist today which can undertake such work satisfactorily, as most of our seismic equipment is not designed to cope efficiently with the low seismic frequencies usually involved at ranges of, say, 10 to 15 miles. I have no hesitation in asserting that neglect of seismic refraction by the geophysicist has cost the oil industry a needless waste of time and money.

SUPPORTING ACTIVITY

Large exploration companies which have field parties of their own employ at least a few geophysicists whose main concern is the review and interpretation of the field results. Other companies employing only contract parties may also have such men on their staffs. Some do not, and rely, perhaps, on one or two geologists to maintain the liaison with the parties and to advise the management on the results of the geophysical work. I have gathered the impression that this is an aspect of our activity which has not received due consideration. Geophysical field work is usually very expensive—parties on seismic work abroad may each cost £ 10,000 to £ 15,000 per month—and it is natural that the companies employing expensive parties should endeavour to secure maximum output in the shortest possible time. In these circumstances the party leaders and computers cannot afford to spend much time on the interpretation of the results, and quite frequently the interpretation submitted by the party leader in his report is accepted without further consideration of the records and the data. It should be borne in mind that no geophysicist is infallible, whether he be the chief of a contract party or of a company-owned party. On more than one occasion has an unsuspected plum been pulled out of the pie when an experienced man has re-examined the results of a field survey, and there is no reason to suppose it will not happen in the future. The process of wringing all possible information from the records, and of resolving all the problems involved in the interpretation, requires hours of ‘pondering’ in which few men on field parties can afford to indulge. I am a firm believer in the art of pondering over geophysical records and data: it can pay handsome dividends.

A certain number of technical institutes and universities distributed over Western Europe are definitely interested in geophysical prospecting, and a few of them work in cooperation with exploration organisations. These academic bodies probably expend a greater proportion of their effort on the examination of field results than most companies can afford the time to do, and for that

reason we sometimes receive useful contributions from them in the fields of computation and interpretation. They can fulfil also a useful function in the correlation of geophysical results obtained in different parts of their respective countries at various times provided, of course, that they are supplied with the necessary data by the organisations which undertook the field work. The support of these bodies by industry cannot help but benefit all concerned.

In the field of instrumental research and development I think we show a tendency to lag. Most contractors, as would be expected, report some activity on this aspect of our work, but the majority of exploration companies who own parties do not undertake serious work in this field. There is a tendency to rely on the resources of our American friends, either for the direct purchase of equipment or for suitable designs on which to manufacture our own. I would like to see the adoption of a more independent attitude in this respect, though I do not mean that we should neglect to keep abreast of all advances in the U.S.A. Remember that the first geophysical instruments for prospecting purposes were designed in Europe. A resurgence of initiative in this field is, I suggest, long overdue.

Although a certain proportion of our overall effort is devoted to short- and long-term research in techniques of geophysical exploration, the proportion itself is disappointingly small. The majority of us are so engrossed in the immediate problem of finding new reserves of oil that we are liable to overlook the possibility that our present techniques will not necessarily continue to serve us satisfactorily in the future. By endeavouring to improve these techniques and our equipment in the semi-empirical fashion prevalent today we can expect to resolve more difficult problems and to reduce our operating costs, but that approach will take us only part way along the road. To go beyond that point we need to develop a clearer understanding of the fundamental processes which govern our present methods and, at the same time, we must not overlook the possibility, however remote it may seem, of developing new techniques for finding oilfields. In the case of seismic surveying, for example, we spend a great deal of time and money in attempts to improve our records and our results in general with an empirical approach dictated partly by our ignorance of the processes of seismic wave propagation and of the true ground motion resulting from a seismic shot. Many other geophysicists appreciate this point besides myself, but they are handicapped by the overwhelming drive to keep every available man on exploration. Our present short-term outlook may eventually harm both ourselves and the industries which we serve. Is it not perfectly reasonable to expect that, by diverting now a small fraction of our effort to both theoretical and practical research on this subject, we might find ourselves all the sooner, and certainly more surely, in a position to produce more effective types of equipment, better techniques of interpretation and a reduction in exploration costs? I have long been associated with large-scale refraction observations involving shots measured in tons rather than in pounds, with parties now costing anything up to £ 15,000 or more per month, and I am

convinced that a research programme which we are now implementing on the lines indicated above will eventually result in noteworthy benefits on this type of work, both for us and for our employers.

A number of eminent geophysicists have expressed difficulty in visualising possible new methods of exploration, but that does not mean that the prospect is a hopeless one. Until the day dawns when someone receives a happy flash of inspiration, however, I believe we should not be wasting our time if we revived our interest in the geochemical method. I hold the view that this method will one day come into its own, despite its chequered career to date. The techniques employed in the application of the method are varied, but the fundamental idea behind them seems thoroughly sound to me. It affords the possibility of detecting oil directly, a factor which will assume greater importance as we are driven to seek our oil in structures of ever-increasing complexity. May I suggest to our colleagues in the technical institutes and in the geophysical departments of universities that here is one line of work which they might consider, which will not cost very much and which they might find rewarding?

I look upon the radioactive method as a variation of the geochemical, but there is another entirely different method which was the subject of heated arguments at a session of the S.E.G. I refer, of course, to the 'Radoil' method, employing radio waves. From considerations based on electromagnetic theory it would seem impossible that effective penetration of the earth strata by radio waves could be realised. However, I confess that I am prepared to entertain the idea that under certain conditions it may be possible to secure penetration to thousands of feet. I recall the difficulty I experienced more than 20 years ago in trying to reconcile the observed energy from a critically refracted seismic wave with expectations based on theory, and that experience makes me chary of accepting blindly the pronouncements of the purist in physical theory. The inventor of the method claims that it works, he announces in the press that an ever-increasing number of clients are being convinced of its effectiveness, and towards the end of last year some field results were published in an oil journal. Though I may risk being termed a gullible person, I find it difficult not to believe that there is something worthwhile in the inventor's claims.

LOOKING AHEAD

What of the future? Will there still be a demand for geophysical prospecting in the years to come? If so, will that demand increase? There appears to be little doubt or that score in the minds of knowledgeable people in Europe today, for almost all anticipate a continued and increasing demand for the geophysicist's services in the future. When one considers a few basic facts their optimism seems justified. Nuclear fission and solar heat are admittedly potential sources of energy, but the day is still far distant when they will be able to compete economically with the present sources of heat and power for the multifarious requirements of our modern society. In the meantime the consumption of oil, quadrupled since 1925, is expected to be more than doubled

again by 1975: and so it will go on for many decades to come. But, as emphasized in a Petroleum Press Service article some months ago, in order to sustain such enormous productions the working stock of the oil industry must be maintained, and this can only be done if oil is discovered at a rate in excess of current production. Without the geophysicist this Herculean task would be quite impossible, and even he is not going to find it easy. Those cunningly-masked fields in which our reserves of the distant future lie will tax his ingenuity to the utmost, but that they *will* be found I have little doubt: the prospecting geophysicist can be rather good at cracking tough nuts!

So let there be no uncertainty. The future for geophysical prospecting is as bright as,—nay, brighter than—it ever was. Declare it aloud, and the way will be paved for a flow of recruits of the right type in the years to come. Remember that the problems of the future will be difficult, so start thinking now on how they will be tackled. Do not be caught unawares by assuming that the other man will solve these problems for you. Remember that geophysics was born in Europe, and in the early days we held the initiative in this science. Why not win back some of this initiative, particularly in the fields of quality and of new techniques? Progress thrives on the competitive spirit, so let us initiate some real, but friendly competition with our friends across the Atlantic, and show less inclination to follow in their footsteps. The secret of our success in the future lies in the three words printed on the back cover of our journal. Their application is far wider than you may originally have thought, and I commend them to your serious consideration.

Quaere et Invenies

ACKNOWLEDGMENT

In my communications to the many people and organisations who helped me in the preparation of this address I expressed my intention to name them in my 'Acknowledgments'. I now realise that this not only a formidable task, but that it would take up much space in this journal. I beg, therefore, that I may be released from this obligation. Throughout the whole period of my investigations I received kindness and helpful cooperation on every hand, from every national community with whom I corresponded. On the implications of this happy experience of mine I need not dwell, for they should be clear to all. May I therefore be permitted merely to express to the various Oil and Mining Companies, the Geophysical Contracting Companies, the Technical Institutes and University Departments, the Government-sponsored Organisations and the Eminent Persons with whom I corresponded or had discussions, my sincere appreciation and thanks,

BRITISH SEISMIC EXPLOSIVES—THEIR STORAGE AND USE IN THE FIELD WITH SPECIAL REFERENCE TO SAFETY IN HANDLING *

BY

S. H. DAVIDSON **, R. WESTWATER **, AND J. HANCOCK **

INTRODUCTION

The first explosive used for commercial purposes was Blackpowder. This is a mixture of potassium nitrate, sulphur and charcoal. It is still used in certain circumstances for blasting rock, but in modern practice its chief use is in safety fuse. Modern blasting is almost completely dependent on detonating explosives which were developed after Alfred Nobel's first exploitation of the detonation of nitroglycerine. His later inventions of dynamite, and blasting gelatine, laid the foundation on which all modern commercial explosives are based.

When an explosive is detonated, a pulse or wave travels from the source of initiation in all directions at a constant speed. The pulse or wave is rather complex and travels faster than sound in the material. It has at its head a region of very high pressure. Behind this there is a region where the chemical reactions take place, the pressure is still high and the density is greater than the original explosive. These reactions produce large quantities of gas at very high temperatures and pressures and the whole process in any particle is over in less than 0.00001 sec. The detonation wave leaves behind it a mass of hot gas which on expanding, forces the rock or whatever media the explosive is used in, to give towards any weakened part. The wave also has the advantage of being supersonic and is really a shock wave supported by the energy released in the chemical reactions going on behind it. As would be expected, this shock pulse does not stop when it is no longer supported by the reaction, but travels out of the explosive into the surrounding rock. This in effect is similar to that of a severe shock or blow and shattering usually results.

Blackpowder does not detonate but burns. Being granular it burns rapidly at all available surfaces, and in confinement the burning speed increases rapidly

* Presented at the Paris Meeting of the European Association of Exploration Geophysicists, May 1953.

** Imperial Chemical Industries Ltd.

as the pressure of the surrounding gas increases. It therefore does not produce the shattering hammer-blow of detonation but rather a heaving action. Flame or heat will ignite Blackpowder, but detonating explosives require a sudden blow which provides a shock wave before they are initiated. Fortunately there are a few substances which on ignition by flame, react so rapidly that they develop detonation waves. Mercury fulminate is an example, and this substance has been used in detonators for many years. When the detonators are inserted into a cartridge of the main charge of explosive and ignited by the flame from a blackpowder fuse or an electronically-ignited match-head, the primary charge in the detonator burns to detonation and the shock wave is transmitted through the tube to the main explosive which then detonates at its characteristic speed.

A cartridge of explosive, therefore, such as is normally used in building up a charge in seismic prospecting, is a reservoir of considerable potential energy. This energy, however, is presented in such a form in the cartridge that it is entirely under the control of the shotfirer and can only be released at his will to do whatever type of work he demands of it. It is really a remarkable thing to think that this amount of energy can be made available in such a form that it can be transported safely in ships or by rail across the globe where it can be stored for prolonged periods until it is called upon to do work. To appreciate just how much energy is available in one 5 lb. stick of Seismic explosive it should be realised that it is equivalent to the fall of 1 ton through 200 ft. or, since the energy is liberated in 33 microseconds, that it is really equivalent in rate of power output to a 20,800,000 Kilowatt generator. Such a power house must, therefore, of necessity be handled prudently and with respect.

Much has been done by the manufacturer to obviate many of the risks involved and the present day commercial explosives are now so designed that if properly handled are completely safe and can be used to good effect with impunity. This applies to both the main explosive charges and the detonators supplied to set them off. Certain other agencies do exist, however, which are capable of causing premature explosions: the chief ones being, of course, chemical instability and friction or percussion forces. It is the responsibility of the manufacturer to eliminate the dangers of chemical instability but it falls on the consumer to see that the explosive is both stored and used properly in the field.

THE MANUFACTURE OF MODERN CIVIL EXPLOSIVES SUCH AS USED FOR SEISMIC PROSPECTING

Apart from the special properties of performance required in explosives for seismic prospecting there are certain aspects of explosive design pertaining to safety that are given special attention by the manufacturer. In the first place the explosive must not only be chemically stable at the time of manufacture but this stability must be maintained throughout prolonged storage periods, in

a large variety of climatic conditions. To ensure stability, all of the raw materials which go into the making of the explosive are carefully specified. They must be chemically pure. The chief explosive ingredient in the seismic gelatines is, of course, nitroglycerine. This material becomes unstable in the presence of acid and care has always to be taken to rid it of any acidic traces before use. It is, therefore, washed several times with weak alkali solutions and water, before it is fit for use, and then only after its stability has been found satisfactory in a special test. The same applies to the nitrocellulose which is present to gelatinise the nitroglycerine. The other ingredients, fuels and metallic oxidising salts, are likewise tested for acidity and general purity. These solids are also carefully checked for grit content as this would increase the hazard both in manufacture and use. In addition to this a special ingredient known to have beneficial stabilising properties is added. This is usually a very weak alkali. This material prevents instability during storage, when if the conditions of storage are bad and very prolonged, some of the nitroglycerine decomposes slowly liberating nitrous fumes. These fumes are immediately neutralised and their catalytic action is destroyed, and further decomposition checked.

All of the finished explosive is subjected to recognised stability tests. The Abel Heat Test is still used and no mixture with a test time of less than 10 min. at a temperature of 160° F. is considered fit for issue. This is law in Great Britain. It should be understood, however, that the heat test is only a quick method of assessing stability but, in fact, heat tests of less than 10 min. need not necessarily give any cause for alarm. In many cases explosives of good stability show low heat tests after tropical storage. Other thermal tests are sometimes used, such as storage of cartridges at 60° C, until decomposition occurs. With some stabilisers this is a matter of years. This is an accelerated test, of course, as explosives are unlikely to meet with such temperatures in the field. Further precautions are also taken in that no formulae are adopted for sale until they have undergone prolonged storage in specially constructed climatic magazines where tests are made for sensitiveness and stability over monthly periods up to sometimes seven years. These magazines are either hot and dry or hot and wet conditioned as required.

It is also important that the explosive cartridges do not exude or leak nitroglycerine. This is reported to have been the cause of many serious accidents in the early days of explosives. With improvements of technique in the manufacture of nitrocellulose and by careful selection of the proper grade, particular attention being paid to viscosity and nitrogen content, it is now possible to make compositions which will not exude even when stored under the most stringent climatic conditions or under pressure. All compositions are tested for exudation during storage in laboratory climatic magazines over long periods of storage before they are adopted as suitable for service.

Frozen cartridges present danger. To offset this the freezing point of nitroglycerine (13.4° C) is depressed by mixing with ethylene glycol dinitrate until

the explosive will not freeze even when stored 10 days at -10° C and seeded with a crystal of nitroglycerine.

Similar precautions are also taken in the manufacture of detonators.

SEISMIC ELECTRIC DETONATORS

Seismic detonators are normally issued with lead mono nitro resorcinate/chlorate fuseheads: such detonators have zero *induction* time when fired at currents not greater than 2 amp. Seismic detonators with lead styphnate fusehead are also available in small quantities; detonators fitted with these fuseheads give zero induction times at firing currents of up to 8 amps or higher. Both fuseheads have a minimum single firing currents of 0.6 amp at 50 milliseconds.

Care is taken in manufacture and packing to ensure correct functioning of the electric detonator. All raw materials and explosive ingredients are very rigidly specified and all are examined and tested according to specification before acceptance. Complete inspection is carried out at various stages in manufacture, e.g. fusehead combs, finished fuseheads, detonators (twice), electric detonators. The electrical resistance of all fuseheads and finished electric detonators is checked. Routine firing tests are carried out on all batches of fuseheads, detonators and electric detonators.

Additional safeguards to the user from the safety point of view are also incorporated. The ends of the detonator leading wires can be obtained twisted together and the bare ends covered by a plastic insulating sheath. The method of packing is such that the detonators are inside the bundle surrounded by the leading wire coils as a protection against blows, etc. Seismic detonators with two lead styphnate fuseheads are also fitted with a paper sleeve between the fusehead and the detonator tube. This gives some measure of protection against electrical discharge from fusehead to the detonator case.

To protect the detonators from stray currents the ends of the leading wires as stated above are twisted together and sheathed. In the routine testing of the fuseheads the "no-fire" current is determined. The no-fire value for our fuseheads is considerably higher than that delivered by approved circuit testers on ohmmeters.

PACKING

The final responsibility of the manufacturer is to ensure that the explosive and accessories are packed in a manner adequately strong and moisture proofed to withstand handling, transport and storage. It is sufficient to say here that the acceptance of commercial explosives as freight for shipment to any part of the globe substantiates the efficiency of the type of packing adopted. It is also known from long experience that this packing adequately protects the contents even in the most trying conditions such as are experienced in tropical countries where stocks of explosives have been stored successfully for periods of years without deterioration. Recently there was occasion to test a sample of explosive returned from some obscure magazine which had actually been made in 1906.

This composition, a gelatine not unlike the present day seismic explosives, was found in all tests to function with unimpaired violence and its stability and physical appearance had not deteriorated. In the case of detonators, care is taken to protect them from undue force or violence caused by careless handling and the design of packing case has only been arrived at after long tests and consultation with the authorities.

As received, therefore, the explosive and detonators are in a safe stable condition suitable for storing for long periods in base or field magazines until such times as they are required for use.

STORAGE: DEPOT MAGAZINES AND TEMPORARY FIELD STORAGE

The storage of explosives and accessories for seismic prospecting probably introduces problems not usually met with in mines and quarries. The following recommendations, however, should always be borne in mind to ensure proper storage conditions which will afford the greatest security against deterioration of stocks or even accidents. Explosives and detonators, of course, cannot be stored in the same magazine and separate storage is required for each. These buildings should be at least 50 yd. apart.

1. The magazine should be constructed if possible of fire-resistant material and its precincts should be kept clear of brush, paper, dried or withered vegetation, etc. as a further precaution against fire. Care should also be taken to ensure that explosives cannot come into contact with protruding nails or metal surfaces. In hot climates it is beneficial to paint the building white or with aluminium paint to assist in reducing the internal temperature. The building should be weatherproof, dry and well ventilated and at all times clean and free from extraneous materials, especially grit and combustibles. It should be provided with a means for securely locking it as a protection against theft or unlawful entry.
2. The explosive should be stored carefully in the cases, right side up, and with space for ventilation between them and the floor, walls and roof. The cases should only be opened when actually required and cartridges should not be stored loosely on the magazine floor. The stock of explosive in the magazine should be used up in rotation according to its age. In this way stocks are used up before they deteriorate. When deterioration does occur to the extent where the floor is contaminated any liquid should be absorbed on sawdust and burned and the floor wiped with methylated spirits and washed with hot water.
3. Smoking in the vicinity of the magazine should be forbidden and no naked lights or means of producing them, e.g. matches, should be allowed in or near the magazine.

If artificial lighting is required, it should be by means of a suitable flash-lamp, or an approved permanently installed electrical system.

4. Only wooden or suitable fibre tools should be used to open cases of explosives. Metal tools such as chisels, hammers, pliers, etc. should not be allowed in the magazine.

The above conditions, of course, apply to a base or depot magazine and cannot always be observed in any temporary field storage. The principles, however, must be observed and the following suggestions are worthy of attention.

Always store detonators and explosives separately.

Do not select a site liable to flooding.

Clear brush and grass for an area of 25 yd. round the temporary storage as a precaution against fire.

Protect the explosives from the direct rays of the sun and also from rain. Stack the cases with an air space between them and the ground and also in such a way as to allow adequate ventilation.

If necessary place a guard to prevent theft and always limit the amount stored to the minimum required for the actual operations on hand.

TRANSPORTATION

Since most of all the explosives used in seismic prospecting are transported into the field by truck it is essential for good safe practice that all crews are familiar with the local regulations concerning the transport of explosives and observe certain precautions which are accident preventing. In the first place the load should never exceed more than 4,000 lb. of explosives, and in no case should it be loaded in excess of 80 % of its rated capacity. All detonators should be separated by a partition from the explosives and the number carried should not be more than 5,000. As in the case of the magazine the interior of the truck should be constructed so that no metal of any kind can come in contact with the explosive. Such metal objects can easily be covered with wood, leather, a tarpaulin or other suitable material. The tank should not be re-fuelled while the truck is loaded with explosives and each truck should be equipped with fire extinguishers. During the loading of the truck the engine should be switched off. The route should be planned carefully to avoid, if possible, centres of habitation and the trucks should not be delayed or stopped unnecessarily at any spot which might cause risk to public property. At all times, even when the load of explosive is only on case (about 50 lb.) of material, the truck should be carefully superintended by a competent person. In some instances it is advisable to carry a notice declaring that the truck is carrying explosive and a red flag is flown.

OUTSIDE SOURCES OF DANGER TO BE GUARDED AGAINST DURING THE HANDLING AND USE OF EXPLOSIVES

The safe use of the explosive in the field is the responsibility of the user. It is essential that all who handle explosives are aware of the dangers involved by wrong practices. This type of hazard is not restricted to explosives but is ever present where a source of energy is made available to mankind. For example, misuse of the normal services of coal-gas or electricity, present in our homes, can have equally dire results. First of all, certain outside agencies

capable of prematurely firing the explosive must be clearly understood and avoided. The chief of these is contamination with foreign materials and frictional and/or percussion forces.

Where satisfactory storage exists there should be no trouble due to contamination or undue deterioration of the explosive. Its stability should, therefore, be unimpaired and give no cause for alarm. It is a wise precaution, however, never to unwrap the cartridges or, if it can be avoided, not to allow operators to cut them up so exposing the composition. If this is done, extraneous matter can come in contact with the explosive which might cause harm. Grit may also enter and the sensitiveness of the explosive to frictional forces or impact will be greatly increased.

Blasting Explosives are sensitive to initiation to detonation by percussion or friction, the initiation being generally due to a combination of both factors: it is not possible, however, to differentiate completely between them. Various tests are applied in which percussion or frictional effects are made to predominate. In some tests personal errors are almost eliminated by adopting the maximum mechanical control: but in others, such as the mallet and broomstick tests, the personal factor manifests itself. The amount of explosive used in these tests is kept at a minimum in order to avoid the cushioning effect of too much explosive.

When an explosive of unknown properties is subjected to any of the above tests, it is generally advisable to test alongside, under exactly the same conditions, an explosive of known sensitiveness and preferably of the same type.

IMPACT AND FRICTION TESTS ON EXPLOSIVES

Laboratory apparatus has been designed to test the sensitiveness of explosives to friction and impact forces and these are described below.

(a) *Fall Hammer Test*

This test gives mainly a measure of sensitiveness to percussion. It is almost entirely mechanically controlled.

The object of the test is to determine the maximum height from which a hammer of known weight can be dropped on to a known quantity of material placed between steel surfaces of specified hardness, so that no detonation or decomposition occurs in a series of tests.

The apparatus used in this test consists essentially of an arrangement by which various hammers of known weight can be dropped from different heights on to a constraint system. Hammers of $\frac{1}{2}$ and 1 kg. weights are released by an electro-magnetic device.

(b) *Torpedo Friction Test*

This test gives a measure of sensitiveness to friction and percussion, friction playing the predominating part. It is largely mechanical, and is intended to supplement, or possibly replace, the mallet and broomstick tests.

The test consists in allowing a torpedo-shaped striker of known weight and composition, to slide down an inclined plane, set at a selected angle, on to a

small sample of the substance mounted on an anvil of known composition. The test is of very wide application, and the torpedo and anvil may be made from a variety of materials such as wood, rubber, plastics and metals: in such cases it is not possible to specify hardness. Tests are carried out by starting the torpedo at decreasing distances from the anvil until the distance is found at which no detonation or decomposition occurs in a series of tests.

For very sensitive explosives a $\frac{1}{4}$ kg. or $\frac{1}{2}$ kg. torpedo, and for insensitive explosives a 5 kg. torpedo is used. The standard torpedo for all other explosives is the 1 kg. steel torpedo.

(c) *The Mallet and Broomstick Tests*

These tests measure the sensitiveness to a combination of friction and percussion. The results obtained by them are affected by personal factors. The material is placed on a specified surface of stone or wood and struck a glancing blow by a rawhide mallet, a hard beechwood mallet or a broomstick, and the number of detonations or decompositions in a series is determined.

(d) *Pendulum Fall Hammer*

The pendulum type fall hammer has recently been used to test the impact sensitiveness of various explosive mixtures on many different types of materials. It not only compares the different explosives but also gives a guide to the safest materials to use with the explosives, e.g. for constructing machines for their manufacture or tools, stemming rods, etc. for use in the field. The apparatus, the hammer of which weighs 310 gm. can be aligned to give a perfectly flat impact by suitable manipulation of the vertical and horizontal adjustments.

To ensure the most sensitive conditions the explosive is arranged in the form of a ring in order to initiate explosion by the adiabatic compression of trapped gas during impact. A number of different materials can be used as the hammer and anvil.

On the basis of work done with nitroglycerine it has been possible to enumerate the properties of materials which determine their order of safety to impact in nitroglycerine by flat impact. In general the hardness, Young's Modulus and density of the materials, are the most important properties. Thus soft materials such as lead are safer than steel or brass since part of the energy of impact is used in their plastic deformation.

Resilient materials with low Young's Modulus such as rubber are safe. Low density woods are also relatively safe but with woods of high density such as *lignum vitae*, it is possible to produce explosion.

(e) *Friction Wheel Apparatus*

A friction wheel type of apparatus has been designed to test the sensitiveness of explosives to initiation to friction when in contact with various metals. In this machine rods of different materials having a groove at one end to hold the explosives are loaded against a spinning wheel travelling with a surface speed of about 21 feet per second. A lever system is attached to the rods and weights are added to force the rods against the wheel. As in the case of the

impact test the ordinary nitroglycerine explosives are fairly sensitive to initiation by frictional heat produced by rubbing surfaces.

The results also indicate that the sensitivity of the explosives to initiation by friction varies with the nature of the rubbing surfaces. In this respect, previous work has shown that the most important properties of materials which bear on the case with which explosions can be produced by friction are their melting points, thermal conductivities and in the case of magnesium and aluminium, their high heats of oxidation.

Of the metals examined the order of sensitivity corresponds to their thermal conductivities, brass being safer than mild steel and stainless steel. A high sensitivity is obtained with aluminium which must be attributed mainly to its high heat of oxidation. In the case of the non-metallic substances, boxwood and nylon, which decompose at relatively low temperatures, no ignitions are obtained at the highest loads. However, it is possible to cause burning of the explosive when combustible materials such as the woods are rubbed against each other. Some sparks can be produced with the usual type of seismic gelatines when they are rubbed at fairly high loads between boxwood surfaces.

DETONATORS

The most sensitive part to mechanical blow is the fusehead and for ignition the implement delivering the blow must be harder than the fusehead bead, i.e. harder than the hardest wood. The sensitiveness has been tested by means of a fall hammer apparatus, laying the detonator horizontally on a steel anvil and transmitting the blow through a steel striker supported on the detonator tube at a point corresponding to the position of the fusehead. 50 % ignitions were obtained with a blow of 925 oz. in. Using the same apparatus the most severe blow available (3,240 oz. in.) failed to fire the detonators when the blow was directed at the end containing the initiating explosive.

FIELD PRACTICE

The handling of explosives in seismic prospecting is at first sight straightforward. As in all other operations in which explosives are used, however, common sense and prudence are necessary if accidents are to be avoided. Credit is due to seismic prospecting crews that during the considerable time this technique has been in use, very few accidents have occurred. Where there has been a report of an accident it is usually at or near the shothole during preparation or loading. The crews should, therefore, be trained and encouraged in the proper handling methods which will afford the maximum margin of safety. The following recommendations are offered as a possible method of standardising field practice to give maximum safety with good results.

(a) Preparation of Charges

Due to the difficulties experienced in pushing seismic charges down through the water and mud usually found in the boreholes, it was evident at an early date that the cartridges for such charges would require to be rigid and where

more than one cartridge was loaded some means of ensuring close contact was necessary to ensure complete propagation.

A large number of methods of linking were examined in the initial stages, comprising, amongst other things:

1. A composite container with screw metal ends, which would be filled with a wrapped cartridge.
2. A stockinette fabric tube which would stretch in the length and contract round the cartridges.
3. A device wherein the end of a column consisted of a sleeve with closed end of half the length of a cartridge, so that cartridges and sleeves could then be added to the required length with the joins in each coming in the centre portion of the other.
4. A tube with collar on one end and recess on the other which would be pinned together, the cartridge at the same time being fixed in position.
5. A complete metal tube with interlocking ends.

All but No. 4 were abandoned as not meeting with the essential requirements of a seismic coupling device.

Initial samples were prepared with two wraps of chipboard, but it was evident that this would not be rigid enough. A preliminary trial with these couplers in a quarry indicated that they would be readily deformed, thus making joining them together a difficult operation. Further sizes were tried with a thicker chipboard and these proved satisfactory. In the assembly of the coupler in the form in which it was originally proposed, the cartridge was half removed from a sleeve. A second sleeve was passed over the protruding end and interlocked with the first sleeve. The whole assembly was fixed together by retaining clips.

Experiences in the field with the clip type of coupler indicated that there was a tendency for the inner cartridge to come loose and while this did not prevent their use it made manipulation a little more difficult. A further disadvantage was having separate components, and it was considered that the device compared unfavourably with the Hercules "Spiralok" coupler. It was, therefore, decided that, as the "Spiralok" coupler was most effective and simple to use, this method be adopted and the necessary licence was obtained from Hercules Company, and the device was manufactured under the name of "Seislok".

When using couplers it is still necessary to ensure close contact to guarantee complete propagation. It should be appreciated that the sensitiveness of explosives of the type used for seismic prospecting, while capable of propagating over gaps of the order of 30 cm. in air, only propagate over smaller gaps when subjected to high hydrostatic heads. The charge should be primed by making a channel for the detonator at an angle of 30° to the long axis just below the end of coupler where the two bottom cartridges are joined and pointing in an upward direction. In doing this the lead wires will not be bent back sharply where they emerge from the detonator tube eliminating the risk

of a short circuit. To secure the lead wires a half hitch should be made right over the detonator. In this way the knot will be protected by the lips of the coupling tube against abrasion. Further half hitches should be made along the length of the charge with the final one near the end of the last cartridge.

LOADING THE SHOTHOLE AND FIRING THE SHOT

The following recommendations are suggested as a basis for good loading and firing practice:

1. Drive shooting truck to vicinity of shothole and park at a safe distance upwind from the hole so that material blown out of the hole is not carried over the trucks. A safe distance is normally 25-50 yd., according to the depth of the hole, the degree of stemming and the amount of explosive used. The shooting truck and the recording truck should also be separated by 25-50 yd.
2. Unload tamping rods and carry them to shothole. Wooden rods with quick detaching brass fitments are preferable. No material should be used that could set up a galvanic action in the shothole, for instance an aluminium rod in alkali water can generate a sufficient potential to initiate an electric detonator.
3. Lower tamping rods down shothole to check for depth and clearance.
4. Lay out shotfiring cable.
5. Short circuit both ends of the cable and connect both to earth. A suitable earth can be obtained by driving a metal rod into the ground. Where the ground is particularly dry earthing can be greatly improved by sluicing with water.
6. On receiving the instructions from the Recorder as to the weight of the explosive charge and the depth at which it is to be fired, unlock detonator storage box, take out detonator and relock box. The detonator leading wires should be kept coiled at this stage.
7. Join the ends of the detonator leading wires together if they are not provided by the manufacturer with a shunt.
8. Unlock explosives chest, take out required weight of explosive and relock chest.
9. Endeavour to restrict the number of personnel round the shothole to three when making up and lowering the charge.
10. Assemble explosive cartridges.
11. Attach the ends of the detonator leading wires to earth.
12. Uncoil the leading wires carefully and lay them along the ground. Do not throw the wires during uncoiling and do not handle the detonator tube.
13. Earth the body by touching an earth metal rod or other suitable earth before handling a detonator tube prior to inserting it into the cartridge.
14. Insert the detonator into the column of cartridges so that it faces the main length of the charge and so that it cannot be withdrawn by strain on the leading wires.

15. Hitch detonator leading wires to cartridge column.
16. Lower the charge into the holes as far as the leading wires will allow.
17. Disconnect the leading wires from the earthed rod and connect them to the shotfiring cable which will also have to be disconnected from earth. Ensure that no short circuit is possible at the join.
18. Keep the exploder ends of the cable earthed until the charge is ready for firing.
19. Lower the charge, checking if necessary that it is in the correct position by the use of the tamping rods. Take care not to damage the leading wires and shotfiring cable during this operation.
20. If explosive charge meets an obstruction when loading do not use the tamping rods to pound the charge or to apply a heavy pressure, use rather a steady pressure. If this does not succeed in moving the charge down the hole the charge should either be fired where it is, or preferably withdrawn and the hole cleared.
21. If water is available pour this down the hole for tamping.
22. Withdraw all personnel from the vicinity of the shothole.
23. Separate exploder ends of shotfiring cable and check circuit. Twist ends of shotfiring cable together again.
24. When ready to fire shot give adequate warning to all personnel and make sure they are all in a safe place.
25. When Recorder is ready untwist shotfiring cable and attach to the terminals of the exploder or shooting box.
26. On receiving the signal from the Recorder fire the shot. Personnel should not be walking about at this moment near the geophones as their foot falls may obscure the recordings.
27. Watch out for any debris that may have been projected upwards from the shothole.
28. Disconnect the shotfiring cable from the exploder or shooting box and twist ends of cable together.
29. If further shots are to be fired in the same hole the hole must be allowed to cool before a fresh charge is inserted in it. The waiting time will depend on the size of the charge and the amount of water in the hole. If available, pour fresh water down the hole to cool it.
30. When shooting has been completed collect all empty wooden cases, cartridge wrappers, and other debris and destroy by burning or else carry away for destruction.
31. See that all fires are extinguished, especially when working in wooded country, scrub, or grassland.
32. Suspend all shotfiring operations on the approach of a thunderstorm. Short circuit shotfiring circuit and retire to a place of safety.
33. Do not operate, if possible, in the vicinity of electric power lines. They may conduct lightning surges from a considerable distance. They may produce a potential in a shotfiring circuit either by induction or by leakage,

and on firing, the detonator leading wires may be blown into them by the explosion, thus causing a danger to personnel from electrocution. These dangers can be reduced by laying out the shotfiring cable at right angles to the transmission line and also by anchoring them securely to the ground. Alternatively, detonating fuse may be used.

34. Close down all wireless transmitters in the neighbourhood when shotfiring. High power commercial transmitters, Radar, etc. may be dangerous in some circumstances up to one mile. Low power transmitters such as Walkie-Talkie may be dangerous in some circumstances up to 100 yards.
35. Do not carry out shotfiring in dust storms as dust can generate sufficient static to initiate electric detonators. Static can also be generated mechanically under some circumstances, for instance, a belt driven machine can build up static on the belt and steam discharging from a nozzle can also do the same. Occurrences of this nature should be avoided as far as possible near the shothole.

DEVELOPMENT OF EXPLOSIVES FOR SEISMIC WORK

Though the use of explosives in seismic prospecting began towards the end of the 1920's in the U.S.A. it was not until 1937 that explosives manufacturers in Great Britain were asked to supply such explosives. Experiences in America had indicated the requirements of suitable explosives, and these varied according to the method being used. In general, however, explosives for seismic work required:

- (a) a power of about 60 % grade strength.
- (b) ability to propagate detonation at high velocity under heads of water which might be as great as 400'.
- (c) considerable stiffness and rigidity in the cartridges.

The first explosive tried was an ordinary commercial gelnite containing about 50 % nitroglycerine. To give the necessary rigidity the explosive was wrapped in 10 turns of waxed manilla paper. This explosive was found to be satisfactory except under heavy heads of water, and experiments showed that propagation difficulties were likely to arise when a file of several cartridges was detonated in holes with more than 50' of water over the explosive. Consideration was, therefore, given to the development of sodium nitrate gelatines of high velocity which would be suitable for geophysical work since this type of explosive was known to have a considerable water resistance. Although sodium nitrate gelatine explosives are usually characterised by low velocity of detonation a number of methods had been developed by Research Department of Nobel Division of Imperial Chemical Industries which gave good promise of producing sodium nitrate gelatines of high velocity.

The most suitable method of attaining high velocity of detonation appeared to be the incorporation in the explosive composition of low density carbonaceous materials. This could be done without special plant or without adding to the cost of production. The most suitable available ingredients were megasse or

bagasse. A composition containing 70 % nitroglycerine, sodium nitrate and megasse was developed and issued to the field after it had shown a satisfactory performance under a water pressure of 60 lb./sq. in. for 18 hours. The new explosive proved satisfactory both under test and in the field and was later given the name "Geobel".

In the manufacture of this explosive containing megasse, this material proved to be undesirably dusty and trials were therefore made substituting bagasse for megasse. The properties of these two substances are similar and the composition containing bagasse was found to be satisfactory under test and convenient to work with on the plant. This composition was therefore adopted and issued to many countries where it proved most satisfactory to the seismic field crews.

Shortly after the development of Geobel a request for a similar explosive of lower power was received and Geobel No. 2 was prepared and tested. Geobel No. 2 was similar to Geobel containing nitroglycerine, sodium nitrate and bagasse, but the percentage of nitroglycerine was reduced and that of sodium nitrate increased, giving a lower power and cheaper cost explosive. At the same time experiments were put in hand to develop a 50 % nitroglycerine composition. For this purpose the standard N.S. Gelignite 50 % nitroglycerine composition was modified by the replacement of a proportion of the woodmeal it contained by bagasse. The properties of the new composition were proved satisfactory and it was adopted for issue as Geobel No. 3.

The heat tests of explosives of the Geobel range though satisfactory were on the low side and it was considered advisable to improve the results obtained on test. This was done by incorporating a small proportion of diammonium phosphate in the explosives.

As developed the Geobels were not low freezing, that is to say the explosives would harden and freeze at temperatures below 10° C. To make them suitable for use in the colder countries a range of low freezing compositions comparable in properties was therefore prepared and issued.

FIELD EXPERIENCE WITH THE GEOBELS

From their development in 1937 until 1949 the Geobels proved entirely satisfactory in the field and thousands of tons were issued and used by seismic crews operating under all types of conditions. Difficulties of supply and transport during the war resulted in these explosives being stored for several years, which is longer than normally recommended, but they stood up well to this storage and only comparatively small quantities had to be destroyed.

A few complaints of premature ignitions were received and in some cases these were traced to misuse while in others there appeared to be the possibility that the practice of using the same hole for several shots might bring about premature explosions during loading into shotholes. Some experiments were therefore made in order to find whether Geobel No. 3, the explosive which was concerned in these complaints, was unduly sensitive to high temperatures.

These experiments showed that at temperatures in the neighbourhood of 150°C a quiet decomposition reaction occurs accompanied by nitrous fumes. This decomposition is similar to what takes place with standard sodium nitrate gelatines at 150°C and shows that Geobel No. 3 is no more likely to decompose due to temperature than any of the ordinary commercial blasting explosives.

Another possible cause of premature ignitions is that in deep holes where the explosives cartridges are subjected to high water pressure the primer cartridge detonates, but because of the pressure causing the remaining cartridges to be less sensitive, these fail to detonate properly and in some cases burning cartridges have been ejected from the boreholes. Tests which have been made on the propagating ability of the Geobels while actually under high hydrostatic pressures of water indicated that they would not fire at high velocity when initiated with ordinary No. 6 or No. 8 detonators, especially if the charges were left for some hours before firing. The tests were done with pressures varying from 10-25 atmospheres and the cartridges were subjected to these pressures for four or more hours and though such tests were considerably more severe than published tests on explosives for seismic prospecting, it was felt that similar conditions might well be experienced in the field, and it was decided to investigate the possibility of developing explosives to meet them.

Until these developments could take shape it was recommended that where the Geobels were subjected to pressures of water in excess of 100 ft., the initiation should be by means of a seismic electric detonator and waterproof primer, as it was found that by using the primer, high velocity in a column of cartridges could be obtained up to 200 ft. head of water and with the primer the cartridge containing this would detonate completely at 600 ft. head of water.

GEOPEX

Up to now the design of gelatine explosives for seismic prospecting, which has resulted in such explosives as the Geobels etc. has been based upon sodium nitrate gelatine explosives, modified by the presence of special carbonaceous combustibles. These special combustibles have had to have the property of retaining air in their pores when subjected to considerable pressure; generally speaking, they are, therefore, characterised by a low density and by the presence of closed air-filled voids. The maintenance of ability to detonate under pressure when initiated by ordinary detonators is associated with the presence of this air. The special combustibles used also afford good sensitiveness and detonation velocity at ordinary pressures.

There is, however, a limit to the pressure which any explosives designed on this basis can withstand before the structure collapses and the special propagating properties are lost and propagation is not always achieved from ordinary detonators.

A further limitation of explosives designed on this basis is that the ability to propagate under pressure falls off rather rapidly if the pressure is maintained for an hour or more, due probably to the gradual displacement or solution

of the air. The majority of shots in seismic prospecting are fired within, say 15 minutes of loading, under which conditions this limitation is unimportant, but sometimes charges have to remain overnight or longer, and if the depth is considerable, there are likely to be failures in these circumstances.

In attempting the design of improved seismic explosives, it appeared that reliance upon the basis of design hitherto used was fundamentally unsound, since the above-mentioned limitations could perhaps be modified, but not removed, unless some other basis of design was found.

A better basis was discovered, when it was found that certain fine inert materials conferred improved high pressure propagation properties on explosives of the gelignite type. An early instance of this type of thing was the discovery, before the war, that 4 % of certain kieselguhrs in blasting gelatine favoured high velocity propagation. On the other hand, such other fine inert substances such as china clay were known to have a contrary effect and even kieselguhr in many explosives other than blasting gelatine had a desensitising action. However, it appeared, on recent hypotheses as to the reaction mechanism in the detonation zone, that the existence of a large surface area should be capable of favouring propagation. The properties of the low-density-combustible type of explosive could, indeed, be explained in this way, whilst, however, there did not appear any special reason why large surface areas of substances other than air should not be equally effective. It was clear that if fine inert solids could be found which would have the desired effect in explosives under hydrostatic pressure, there was no reason why the explosives should not remain satisfactory at very great depths, and up to such periods of time as might be needed for serious penetration of the explosive by water, and the consequent fundamental alteration in its composition. As regards this last, it now appears that the low density type of gelatine hitherto considered essential, is, in fact, undesirable, since it is more easily and rapidly penetrated by water.

Experimental investigation of the application of fine inert substances in explosives was actively pursued, and at an early stage it was found that a small percentage of barytes had a marked effect on the propagation of explosives under hydrostatic pressures. Since suitable forms of barytes were cheap and non-toxic, experiments were pursued as rapidly as possible towards the design of a practical explosive for seismic prospecting.

Early tests indicated that the incorporation of barytes* in the explosive composition gave outstanding results under water pressure, and it was necessary to develop suitable testing equipment. This consisted of steel tubes in which the explosives could be fired while in water under pressure, with the necessary glands for leading in the wires to the initiating detonator and the velocity-recording leads from the microtimer, other equipment consisting of a pressure pump and pressure manifold to which charges could be connected for application of the desired pressure. Cocks were provided so that the charges could

* Patents applied for in several countries.

be sealed off before removal from the manifold, and the firing was done with the charges still under pressures. The tests were made with 2" diameter cartridges in Seislok containers and three cartridges were used separated from each other by small gaps.

Under test it was found that with 5 % barytes in the composition sodium nitrate gelignites of 50 % to 75 % nitroglycerine content gave excellent results under pressure when initiated by the normal aluminium cased detonators. Not only did suitable compositions propagate at high velocity at pressures equivalent to depths as great as 2,750 feet, but also good propagation characteristics were maintained after they had been subjected to high pressures for periods as long as 24 hours. These results are, of course, very much better than have been obtained with any explosives based on low density combustibles.

It is interesting to note that the results obtained under pressure with the explosive containing barytes were remarkably different according as copper or aluminium tube detonators were used. This applied irrespective of the type of filling of the detonator. It was also found that the difference between copper and aluminium detonators is appreciable in other types of explosive, for example, Geobel types, so that it can now be asserted quite definitely that seismic detonators should be of the aluminium tube type unless a stronger type of copper detonator is available. Continued testing of the new composition, which has been called "Geophex", indicated that at pressures equivalent to depths of the order of 1,800 ft. propagation is complete after five or six months' hot dry storage, all the velocity of detonation readings being in the region of 6,800 metres per second. The sensitiveness to propagation from cartridge to cartridge was also found to be satisfactory after six months' hot dry storage, and this composition should therefore prove most satisfactory in the field. The development of Geophex has been a triumph for the Research team working on seismic explosives, and from the tests carried out there is no doubt but that this explosive will prove suitable for the most rigorous conditions of use in seismic work.

EXPLOSIVES OF HIGHER INTRINSIC SAFETY FOR SEISMIC PROSPECTING

There is today a trend in explosives manufacture to use more and more ammonium nitrate as a source of energy and less and less nitroglycerine. In seismic prospecting the large diameter of the cartridges generally used favours the use of these less sensitive ammonium nitrate explosives as propagation is much more readily maintained in large rather than small cartridges. It is necessary, however, to use a more sensitive priming composition to set off the charge as this in itself is not sensitive to initiation by a detonator. As ammonium nitrate is very hygroscopic the explosive requires to be protected in a metallic hermetically sealed container. This, of course, has the advantage of being rigid and not deformable. It stands up to moisture as well as being waterproof and is safely and easily handled in the field. The metallic containers are so designed as to form an articulated charge. The Nobel Division of Imperial Chemical

Industries have at the moment a large field scale trial of this type of explosive device in hand. It is called Seismex. It is hoped that Seismex will become available in a variety of diameters for seismic prospecting. The tins can be guaranteed to withstand indefinite storage under 300 ft. of water. For the deeper holes Geophex will be necessary.

THE PEOPLE WHO USE THE EXPLOSIVES

We have discussed the care taken in the manufacture of the explosives to ensure safety in the field, transport and storage. We have also outlined the proper procedure for storage, transport and use as well as giving some idea of the outside agencies that are to be guarded against, showing roughly the margin of safety that exists when friction or impact forces are brought to bear on explosives. What further precautions remain, therefore, you ask, to ensure the safe working with explosives in the field? One thing, and that is the choice and training of the personnel. If this is not done with care the best set of rules in the world will mean nothing. The men who handle explosives should be picked for their intelligence and good sound common sense. They should be told just what explosives are and just what sort of treatment they can be expected to stand. It should also be made clear to them what sort of treatment they won't stand. Some men will show a better aptitude than others but even those men after they have gained experience must be constantly reminded and constantly trained. A novice should be told exactly what his duties are and when he works with explosives he should be under the constant eye of a trained man. The type of man who professes great knowledge and fearlessness with explosives should be avoided. He is usually reckless to the point of being completely irresponsible and is a constant source of danger to his workmates. Training and instruction of the man should be thorough and careful. Every opportunity should be taken to alert the men to the dangers of slipshod or careless methods while not alarming them to the point of making them nervous. In addition to day to day instruction personally carried out by experienced hands, pamphlets in simple language and instructive talks are of great value. Where any doubts exist, explosives manufacturers have specially trained technical service staffs available in the field and these should be consulted without hesitation.

SUR UNE METHODE ANALYTIQUE DE CALCUL DE L'ANOMALIE REGIONALE *

PAR

V. BARANOV **

• ABSTRACT

The common notion, that the regional anomaly must be as regular as possible, can be translated into mathematical language by requiring that the regional anomaly shall be represented, over a not too large area, by a surface of the second or of the third degree. The residual anomaly is commonly defined by the requirement that its horizontal dimensions must be as small as possible. This implies that also its amplitude should be small. This requirement may be moulded into a mathematical form by stating that the square of the difference between the Bouguer anomaly and the regional anomaly, integrated over a certain area, must be a minimum. On these two definitions an analytic method is based for deriving the regional anomaly. Practical computation procedures are presented.

Le calcul de l'anomalie régionale est une des questions très épineuses de l'interprétation gravimétrique. Tout le monde sait très bien ce qu'est l'anomalie régionale, on en parle souvent, de nombreuses méthodes ont été proposées pour sa construction, les géophysiciens et les compagnies ont chacun leurs méthodes préférées, mais on est encore bien loin d'une solution définitive. D'ailleurs, peut-il en être autrement? Les problèmes que la géophysique est appelée à résoudre sont si variés, les conditions naturelles si différentes qu'il semble illusoire de chercher une solution universelle.

S'il en est ainsi, nous reprochera-t-on d'en présenter une de plus? Loin de moi est l'idée d'en préconiser l'emploi quel que soit le cas pratique. Mais je suis persuadé que cette méthode que j'appellerais volontiers „analytique” peut rendre service dans mainte occasion.

Il est inutile de s'attarder trop longuement sur la définition de l'anomalie régionale, mais il faut en dire quelques mots pour préciser le point de départ de nos raisonnements.

Calculer l'anomalie régionale consiste à décomposer l'anomalie de Bouguer B en deux composantes $B = R + A$ de telle façon que la composante R — anomalie régionale — soit la plus régulière possible, tandis que le terme A représente l'ensemble des anomalies résiduelles qui doivent être les moins étendues possible.

En appelant l'anomalie régionale „régulière ou étendue” nous voulons dire

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** Compagnie Générale de Géophysique.

que la pente de sa surface représentative ne doit pas varier trop rapidement. En d'autres termes, les secondes dérivées de R doivent être faibles en valeur absolue.

Cette condition définit tout de suite l'aspect des isogammes qui représentent l'anomalie régionale. En effet, „secondes dérivées faibles” signifient géométriquement „faible courbure”. Par conséquent, les isogammes de l'anomalie régionale doivent présenter une faible courbure et être très régulièrement espacées.

L'anomalie qui remplit ces conditions intéresse une vaste région, donc, elle est provoquée soit par une cause très profonde, soit par une cause très régulièrement variable dans l'espace. En fait ceci est une autre définition de l'anomalie générale, peut-être même plus immédiate que la première. Malheureusement, elle n'est pas d'une grande utilité pratique, car dans l'ignorance où nous sommes de ces causes nous ne pouvons pas trouver de moyens de discrimination autres que le critère de régularité. Nous sommes donc obligés de partir de la première définition pour calculer l'anomalie régionale.

Il va sans dire que cette définition est assez vague: elle est purement qualitative. D'ailleurs, une même anomalie peut être considérée comme suffisamment régulière ou non suivant le cas. Lorsqu'on fait une étude de reconnaissance couvrant une vaste région, l'anomalie isostatique est peut-être la seule régionale qui se justifie. Par contre, pour une étude de détail, même des structures d'étendue moyenne peuvent être incorporées dans l'anomalie régionale, si l'on ne veut laisser subsister dans la différence $B - R$ que des anomalies très localisées.

La notion habituelle de régularité se traduit en mathématique par la condition d'analyticité. Voici ce que nous voulons dire. Une courbe, ou une surface régulière, est une courbe ou une surface prolongeable. Exemple: un cercle. Dès qu'on connaît un petit arc de cercle, on peut en le prolongeant construire le cercle entier. Une telle fonction prolongeable est analytique et sa propriété fondamentale est d'admettre un développement en une série de puissances.

Nous supposons que l'anomalie régionale est une fonction analytique, puisqu'elle est régulière. Nous pouvons essayer de chercher son expression sous la forme d'une série de puissances. En réalité, nous ne calculerons pas tous les termes de cette série: nous nous limiterons, par exemple, à des termes de deux ou de trois premiers degrés, et nous négligerons le reste. Ceci revient à représenter l'anomalie régionale comme une surface du second ou du troisième degré.

Pour nous rendre compte du genre de simplification que nous faisons ainsi, supposons d'abord que nous négligeons tous les termes sauf ceux du premier degré. Alors, notre surface est un plan incliné. Or, il n'est pas déraisonnable de représenter en première approximation l'anomalie régionale comme un plan incliné, surtout s'il s'agit d'une région peu étendue. En effet, nous avons dit que l'anomalie régionale est caractérisée par des dérivées secondes faibles en valeur absolue. En les égalant à zéro on obtient un plan incliné.

Si nous ne les négligeons pas, mais supposons seulement que les dérivées

secondes sont constantes, nous obtenons au lieu d'un plan incliné, un paraboloïde — une surface de second degré. Enfin, nous pouvons même admettre que les dérivées secondes varient légèrement ce qui nous conduit à représenter l'anomalie régionale par une surface du troisième degré. Ainsi donc, nous nous proposons de remplir la condition de régularité en assimilant l'anomalie régionale à une surface de second ou de troisième degré.

Il est à peine besoin de mentionner qu'une telle représentation ne peut être valable que dans une région assez limitée au voisinage de l'origine choisie, par exemple, au centre de l'aire prospectée. Découpons, alors, dans cette région un rectangle de côtés $2a$ et $2b$ (Fig. 1) couvrant toute ou une partie de l'aire pros-

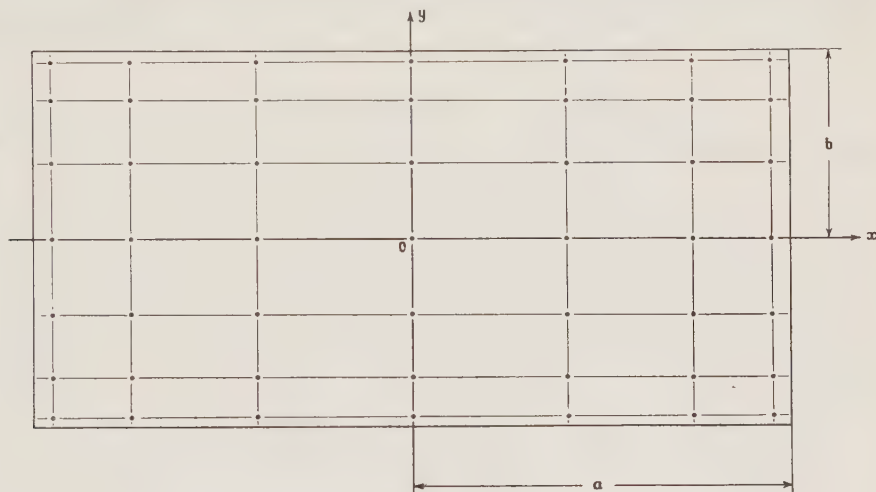


Fig. 1.

pectée. Prenons l'origine de coordonnées rectangulaires (x, y) au centre du rectangle et posons

$$R = C_{00} + C_{10} \frac{x}{a} + C_{01} \frac{y}{b} + C_{20} \left(\frac{x}{a} \right)^2 + C_{11} \frac{x}{a} \frac{y}{b} + C_{02} \left(\frac{y}{b} \right)^2 + \\ + C_{30} \left(\frac{x}{a} \right)^3 + C_{21} \left(\frac{x}{a} \right)^2 \left(\frac{y}{b} \right) + C_{12} \left(\frac{x}{a} \right) \left(\frac{y}{b} \right)^2 + C_{03} \left(\frac{y}{b} \right)^3$$

Nous nous proposons donc de représenter l'anomalie régionale R sous cette forme mathématique à l'intérieur de l'aire rectangulaire que nous venons de définir.

La forme du rectangle est quelconque. Nous avons mis en évidence les longueurs a et b dans la formule ci-dessus précisément pour simplifier et pour généraliser les calculs qui vont suivre. En posant

$$\xi = \frac{x}{a} \quad \eta = \frac{y}{b}$$

on obtient une formule plus simple

$$R = C_{00} + C_{10} \xi + C_{01} \eta + C_{20} \xi^2 + C_{11} \xi \eta + C_{02} \eta^2 + \\ + C_{30} \xi^3 + C_{21} \xi^2 \eta + C_{12} \xi \eta^2 + C_{03} \eta^3$$

Les variables ξ et η peuvent prendre toutes les valeurs comprises entre -1 et $+1$. Notre tâche immédiate consiste à calculer les coefficients C_{ik} .

Nous utiliserons dans ce but la seconde partie de la définition de l'anomalie régionale. Nous avons, en effet, demandé que la différence $B - R = A$, c'est-à-dire l'ensemble des anomalies résiduelles, soit la moins étendue possible. Or, une anomalie de faible étendue est nécessairement de faible amplitude. Donc l'anomalie résiduelle A est relativement petite en valeur absolue.

Mathématiquement on peut exprimer cette condition en demandant que l'intégrale

$$\Psi = \iint (B - R)^2 d\xi d\eta$$

étendue à l'aire du carré

$$\begin{aligned} -1 &\leq \xi \leq +1 \\ -1 &\leq \eta \leq +1 \end{aligned}$$

soit minimum. L'anomalie régionale R épousera alors aussi bien que possible l'anomalie de Bouguer B .

La condition du minimum exige l'annulation des dérivées par rapport aux inconnues C_{ik} . Les dérivées sont faciles à calculer. On trouve d'une façon générale :

$$+ \frac{1}{2} \frac{\delta \Psi}{\delta C_{ik}} = \iint (R - B) \frac{\delta R}{\delta C_{ik}} d\xi d\eta = \iint (R - B) \xi^i \eta^k d\xi d\eta = 0$$

ou

$$\iint R \xi^i \eta^k d\xi d\eta = A_{ik}$$

avec

$$A_{ik} = \iint B \xi^i \eta^k d\xi d\eta.$$

Calculons d'abord les intégrales où figure la fonction

$$R = \sum C_{mn} \xi^m \eta^n$$

On obtient successivement

$$\begin{aligned} A_{ik} &= \iint R \xi^i \eta^k d\xi d\eta = \\ &= \iint \xi^i \eta^k \sum C_{mn} \xi^m \eta^n d\xi d\eta = \\ &= \sum C_{mn} \int_{-1}^{+1} \xi^{i+m} d\xi \int_{-1}^{+1} \eta^{k+n} d\eta \end{aligned}$$

Or, l'intégrale $\int_{-1}^{+1} \xi^{i+m} d\xi$ est nulle chaque fois que l'exposant $i + m$ est im-

pair. Sinon sa valeur est $\frac{2}{i+m+1}$

Ceci s'applique également à l'intégrale

$$\int_{-1}^{+1} \eta^{k+m} d\eta = \begin{cases} 0 & \text{si } k+n \text{ est impair} \\ \frac{2}{k+n+1} & \text{si } k+n \text{ est pair} \end{cases}$$

Par conséquent, il n'y a que peu de termes dans l'expression de A_{ik} qui ne sont pas nuls. En posant i et $k = 0, 1, 2, 3$ on obtient 10 équations linéaires pour calculer 10 coefficients inconnus. D'ailleurs, ce système se décompose en quatre groupes indépendants. Voici ces équations:

$$\text{I.} \quad \frac{4}{9} C_{11} = A_{11}$$

$$\text{II.} \quad \left\{ \begin{array}{l} 4 C_{00} + \frac{4}{3} C_{20} + \frac{4}{3} C_{02} = A_{00} \\ \frac{4}{3} C_{00} + \frac{4}{5} C_{20} + \frac{4}{9} C_{02} = A_{20} \\ \frac{4}{3} C_{00} + \frac{4}{9} C_{20} + \frac{4}{5} C_{02} = A_{02} \end{array} \right.$$

$$\text{III.} \quad \left\{ \begin{array}{l} \frac{4}{3} C_{10} + \frac{4}{5} C_{30} + \frac{4}{9} C_{12} = A_{10} \\ \frac{4}{5} C_{10} + \frac{4}{7} C_{30} + \frac{4}{15} C_{12} = A_{30} \\ \frac{4}{9} C_{10} + \frac{4}{15} C_{30} + \frac{4}{15} C_{12} = A_{12} \end{array} \right.$$

$$\text{IV.} \quad \left\{ \begin{array}{l} \frac{4}{3} C_{01} + \frac{4}{9} C_{21} + \frac{4}{5} C_{03} = A_{01} \\ \frac{4}{9} C_{01} + \frac{4}{15} C_{21} + \frac{4}{15} C_{03} = A_{21} \\ \frac{4}{5} C_{01} + \frac{4}{15} C_{21} + \frac{4}{7} C_{03} = A_{03} \end{array} \right.$$

En résolvant ces équations on obtient les expressions des coefficients C_{ik} qui s'expriment linéairement en fonction des intégrales A_{ik} .

$$C_{00} = \frac{7}{8} A_{00} - \frac{15}{16} (A_{20} + A_{02})$$

$$\left\{ \begin{array}{l} C_{10} = \frac{15}{16} (6 A_{10} - 7 A_{30} - 3 A_{12}) \\ C_{01} = \frac{15}{16} (6 A_{01} - 7 A_{03} - 3 A_{21}) \end{array} \right.$$

$$\left\{ \begin{array}{l} C_{20} = \frac{15}{16} (3 A_{20} - A_{00}) \\ C_{11} = \frac{9}{4} A_{11} \\ C_{02} = \frac{15}{16} (3 A_{02} - A_{00}) \end{array} \right.$$

$$\left\{ \begin{array}{l} C_{30} = \frac{35}{16} (5 A_{30} - 3 A_{10}) \\ C_{21} = \frac{45}{16} (3 A_{21} - A_{01}) \\ C_{12} = \frac{45}{16} (3 A_{12} - A_{10}) \\ C_{03} = \frac{35}{16} (5 A_{03} - 3 A_{01}) \end{array} \right.$$

En ce qui concerne les intégrales

$$A_{ik} = \iint B \xi^i \eta^k d\xi d\eta$$

elles ne peuvent être calculées que par une méthode approchée, car l'anomalie de Bouguer B est donnée graphiquement. C'est la méthode d'intégration de Gauss qui paraît la plus maniable et qui nous a donné les résultats les plus précis.

Rappelons rapidement en quoi elle consiste.

Soit $\int_{-1}^{+1} f(x) dx$ l'intégrale à calculer. Remplaçons-la par une somme

$$\int_{-1}^{+1} f(x) dx = \sum_{\nu=1}^n \lambda_{\nu} f(x_{\nu})$$

où λ_{ν} sont les n coefficients et x_{ν} autant de valeurs de la variable x qui doivent être calculés, les premiers et les secondes, une fois pour toutes. Si la somme comporte n termes, nous avons $2n$ inconnues à déterminer; il nous faudra donc pour cela $2n$ conditions.

En général, l'égalité ci-dessus n'est qu'approchée, mais nous pouvons demander à ce qu'elle soit exacte si l'on pose

$$f(x) = x^r \text{ avec } r = 0, 1, 2, \dots, 2n - 1$$

Alors, l'égalité reste évidemment rigoureuse, si $f(x)$ est un polynôme quelconque, pourvu que son degré ne dépasse pas $2n - 1$. De cette façon nous introduisons $2n$ conditions qui nous fournissent $2n$ équations pour calculer les inconnues λ_v et x_v .

Je ne peux pas insister plus longuement sur cette méthode d'intégration, la question n'ayant que peu de rapports avec la géophysique. Je renvoie, pour plus de détail, par exemple, à l'ouvrage de Tomlison-Fort „Calcul des différences finies” *.

L'expérience nous a montré que pour obtenir une très bonne précision, il suffit de poser $n = 7$. Voici, alors, les valeurs des abscisses canoniques et des coefficients correspondants :

$x = 0$	$\lambda = 0,208\ 980$
$\pm 0,405\ 846$	$0,190\ 915$
$\pm 0,741\ 532$	$0,139\ 853$
$\pm 0,949\ 108$	$0,064\ 742$

Armés de cette formule nous pouvons nous attaquer à l'intégrale

$$\begin{aligned}
 A_{ik} &= \int \int B(\xi, \eta) \xi^i \eta^k d\xi d\eta = \\
 &= \int_{-1}^{+1} \eta^k d\eta \int_{-1}^{+1} B(\xi, \eta) \xi^i d\xi
 \end{aligned}$$

En commençant l'intégration par rapport à la variable ξ remplaçons f par $B(\xi, \eta) \xi^i$. Il vient

$$\int_{-1}^{+1} B(\xi, \eta) \xi^i d\xi = \sum_{(v)} \lambda_v \xi_v^i B(\xi_v, \eta)$$

et, par suite, d'une façon analogue

$$\begin{aligned}
 A_{ik} &= \sum_v \lambda_v \int_{-1}^{+1} B(\xi_v, \eta) \eta^k d\eta = \\
 &= \sum_v \sum_\rho \lambda_v \lambda_\rho \xi_v^i \eta_\rho^k B(\xi_v, \eta_\rho)
 \end{aligned}$$

Malgré l'écriture quelque peu compliquée, cette formule est en réalité très simple. Les 7 abscisses canoniques ξ_v et 7 ordonnées η_ρ forment un réseau représenté sur la Fig. 1. Les valeurs

$$B(\xi_v, \eta_\rho) = B_{v\rho}$$

* Tomlinson Fort: Finite Differences and Difference Equations in the Real Domain, Oxford, Clarendon Press, 1948.

doivent être relevées aux 49 sommets de ce réseau. C'est le seul relevé à faire pour calculer l'anomalie régionale dans la zone rectangulaire. Après avoir multiplié ces valeurs par les coefficients

$$\lambda_\nu \xi_\nu^i \lambda_\rho \eta_\rho^k$$

calculés une fois pour toutes, on obtient la valeur de A_{ik} .

On peut d'ailleurs porter les valeurs des A_{ik} dans les expressions des C_{mn} pour obtenir les coefficients directement en fonction de 49 valeurs canoniques de l'anomalie de Bouguer. Ainsi, on obtient les formules :

$$\begin{aligned} C_{00} &= \frac{1}{16} \sum \sum \lambda_\nu \lambda_\rho (14 - 15 \xi_\nu^2 - 15 \eta_\rho^2) B_{\nu\rho} \\ \left\{ \begin{aligned} C_{10} &= \frac{15}{16} \sum \sum \lambda_\nu \lambda_\rho \xi_\nu (6 - 7 \xi_\nu^2 - 3 \eta_\rho^2) B_{\nu\rho} \\ C_{01} &= \frac{15}{16} \sum \sum \lambda_\nu \lambda_\rho \eta_\rho (6 - 3 \xi_\nu^2 - 7 \eta_\rho^2) B_{\nu\rho} \end{aligned} \right. \\ \left\{ \begin{aligned} C_{20} &= \frac{9}{4} \sum \sum \lambda_\nu \lambda_\rho (3 \xi_\nu^2 - 1) B_{\nu\rho} \\ C_{11} &= \frac{9}{4} \sum \sum \lambda_\nu \lambda_\rho \xi_\nu \eta_\rho B_{\nu\rho} \\ C_{02} &= \frac{15}{16} \sum \sum \lambda_\rho \lambda_\rho (3 \eta_\rho^2 - 1) B_{\nu\rho} \end{aligned} \right. \\ \left\{ \begin{aligned} C_{30} &= \frac{35}{16} \sum \sum \lambda_\nu \lambda_\rho \xi_\nu (5 \xi_\nu^2 - 3) B_{\nu\rho} \\ C_{21} &= \frac{45}{16} \sum \sum \lambda_\nu \lambda_\rho \eta_\rho (3 \xi_\nu^2 - 1) B_{\nu\rho} \\ C_{12} &= \frac{45}{16} \sum \sum \lambda_\nu \lambda_\rho \xi_\nu (3 \eta_\rho^2 - 1) B_{\nu\rho} \\ C_{03} &= \frac{35}{16} \sum \sum \lambda_\nu \lambda_\rho \eta_\rho (5 \eta_\rho^2 - 3) B_{\nu\rho} \end{aligned} \right.$$

Le problème est dès lors résolu, tout au moins théoriquement. Nous avons calculé les valeurs des coefficients C_{mn} . Par conséquent, nous sommes en possession de la formule à l'aide de laquelle on peut calculer l'anomalie régionale en tout point de la région considérée.

Il nous reste à examiner ce problème sous un angle pratique. Comment organiser les calculs, pour les rendre simples, rapides et mécaniques.

Les coefficients des $B_{\nu\rho}$ dans les expressions de C_{mn} sont calculés une fois pour toutes. Nous les disposons sous forme d'un tableau comportant 7 lignes et

7 colonnes (Fig. 2) formant cases. On inscrit dans chaque case, au-dessous du coefficient numérique, la valeur correspondante de $B_{\nu\rho}$ relevée sur la carte de l'anomalie de Bouguer et on fait une multiplication cumulative ce qui fournit la valeur de C . Il y a en tout 10 tableaux pour calculer une surface du 3e degré; 6 tableaux pour une surface de 2e degré. Il faut environ 3 heures à un calculateur pour faire ce calcul.

Après avoir calculé les coefficients de la formule

$$R = \sum C_{mn} \xi^m \eta^n$$

Mission						
10 ⁵ c ₀₀ =						
-1369	-1760	-613	+164	-613	-1760	-1369
-1760	-1217	+2190	+4204	+2190	-1217	-1760
-613	+2190	+8527	+11501	+8527	+2190	-613
+164	+4204	+11501	+15285	+11501	+4204	+164
-613	+2190	+8257	+11501	+8257	+2190	-613
-1760	-1217	+2190	+4204	+2190	-1217	-1760
-1369	-1760	-613	+164	-613	-1760	-1369

Fig. 2.

il faut construire cette anomalie régionale. Il serait évidemment trop long de calculer R pour chaque station effectivement faite sur le terrain. Un procédé beaucoup plus rapide consiste à appliquer la méthode des différences finies. Voici comment nous procédons.

L'aire rectangulaire est partagée en 20×20 rectangles élémentaires (Fig. 3) et le calcul de l'anomalie régionale se fait pour les sommets de ces petits rectangles. Les abscisses et les ordonnées de ces points sont en progression arithmétique avec

$$\Delta \xi = \Delta \eta = 0,1$$

Le polynôme $R(\xi, \eta)$ étant de 3e degré et les points étant régulièrement répartis, les troisièmes différences

$$\Delta^3 R(\xi, \eta)$$

sont constantes. C'est cette circonstance qui simplifie considérablement les calculs.

Pour comprendre la marche du calcul, donnons d'abord à ξ une valeur fixe, par exemple, $\xi = -1$ — valeur qui correspond au bord gauche du grand

rectangle. Alors, R est un polynôme de troisième degré seulement en η , — variable dont les valeurs forment une progression arithmétique.

Le procédé habituel et bien connu, pour calculer les valeurs du polynôme dans de pareils cas, consiste à construire le tableau de différences successives:

$R(1,0)$		
$R(0,9)$	$\Delta R(1,0)$	
$R(0,8)$	$\Delta R(0,9)$	$\Delta^2 R(1,0)$
$R(0,7)$	$\Delta R(0,8)$	$\Delta^2 R(0,9)$
...	...	...

La troisième différence $\Delta^3 R$ reste constante; nous ne l'avons pas écrite. Les secondes différences sont en progression arithmétique et sont faciles à calculer une fois connue la valeur de $\Delta^2 R(1,0)$. On calculera, ensuite, la valeur de

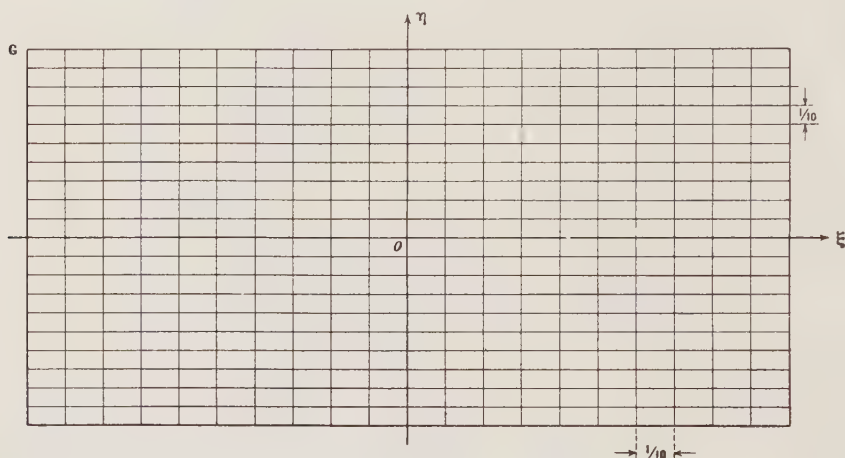


Fig. 3.

$\Delta R(1,0)$ et toute la colonne de premières différences. Enfin, on calculera la première colonne.

Finalement, on voit que, pour calculer les 21 nombres qui figurent dans la première colonne, il suffit de calculer à l'avance les têtes de colonnes soulignées, soit les valeurs de

$$R(1,0) \quad \Delta R(1,0) \quad \Delta^2 R(1,0) \quad \text{et} \quad \Delta^3 R$$

On peut procéder de même pour chaque colonne et, évidemment, pour chaque ligne.

On n'a d'ailleurs pas besoin de calculer les quatre valeurs de départ séparément pour chaque colonne. En effet, on peut les obtenir par le même procédé des différences. Et il est aisé de voir que le nombre total suffisant de valeurs de départ est de 10. C'est d'abord la valeur de l'anomalie au point G dans le coin gauche supérieur (Fig. 3) et les différences de trois premiers ordres. La

La fig. 5 représente seulement le coin gauche supérieur de la feuille de calcul réelle. Pour faciliter les explications nous avons désigné les cases par des lettres à deux indices. Chaque case notée R_{ik} et entourée d'un cadre gras correspond à un sommet du réseau de la fig. 3 et toute la feuille comporte 21×21 cases à cadre gras. Les espaces intermédiaires ainsi que les cases supplémentaires M en haut, et N à gauche sont réservées à des calculs auxiliaires.

On commence par remplir les cases C . La première valeur C_{11} est déjà calculée (feuille Fig. 4). On a, ensuite,

$$\begin{aligned} C_{12} &= C_{11} + a, & C_{21} &= C_{11} + b \\ C_{22} &= C_{11} + a + b \end{aligned}$$

et, en général,

$$C_{ik} = C_{11} + (k - 1)a + (i - 1)b$$

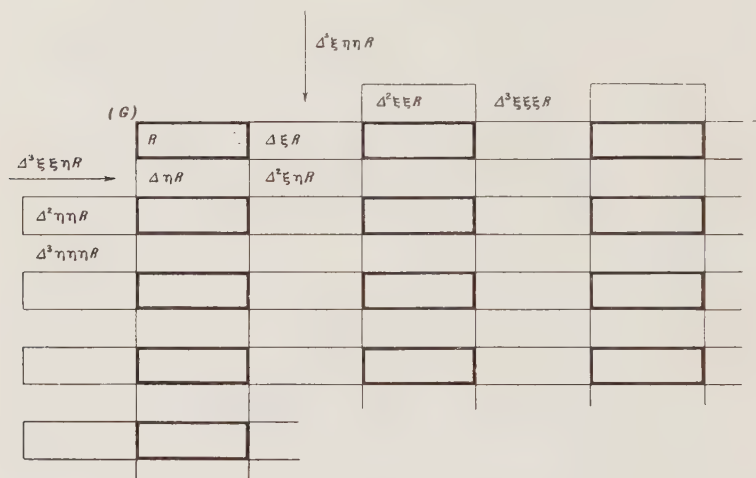


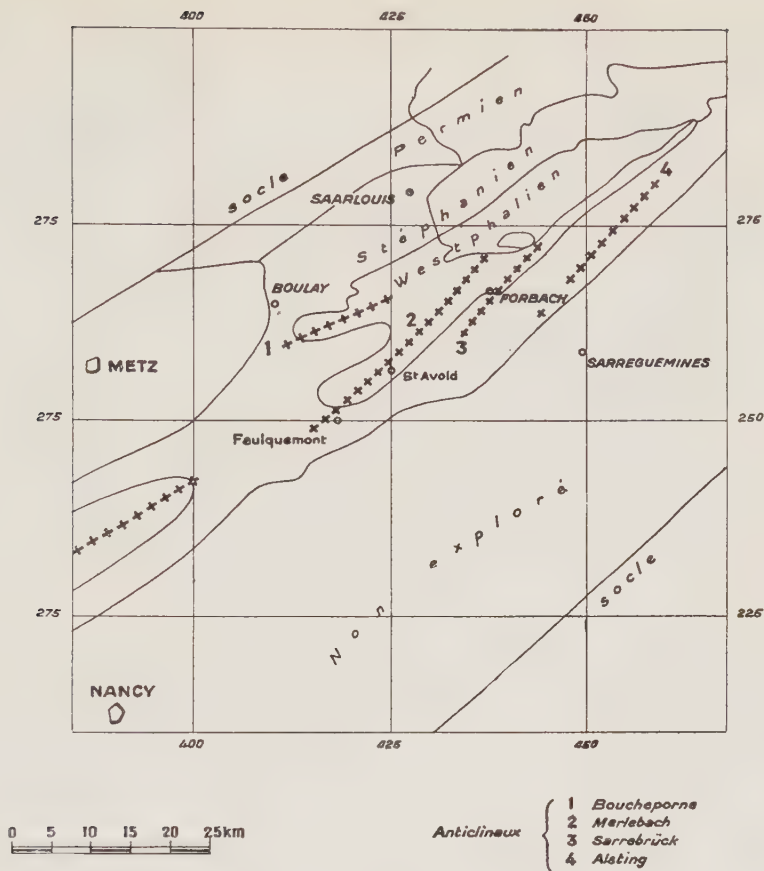
Fig. 5bis. Inscription des dix valeurs de départ.

Ensuite, on remplit les cases M et N d'après le schéma suivant

$$\begin{aligned} M_2 &= M_1 + c & N_2 &= N_1 + d \\ M_3 &= M_2 + c & N_3 &= N_2 + d \\ &\dots\dots\dots & &\dots\dots\dots \end{aligned}$$

Ces valeurs permettent de calculer les A et les B :

$$\begin{aligned} A_{12} &= A_{11} + M_1 & B_{21} &= B_{11} + N_1 \\ A_{13} &= A_{12} + M_2 & B_{31} &= B_{21} + N_2 \\ &\dots\dots\dots & &\dots\dots\dots \\ A_{21} &= A_{11} + C_{11} & B_{12} &= B_{11} + C_{11} \\ A_{31} &= A_{11} + C_{21} & B_{22} &= B_{21} + C_{21} \\ &\dots\dots\dots & &\dots\dots\dots \end{aligned}$$



Carte no. 1. Carte Géologique schématique.

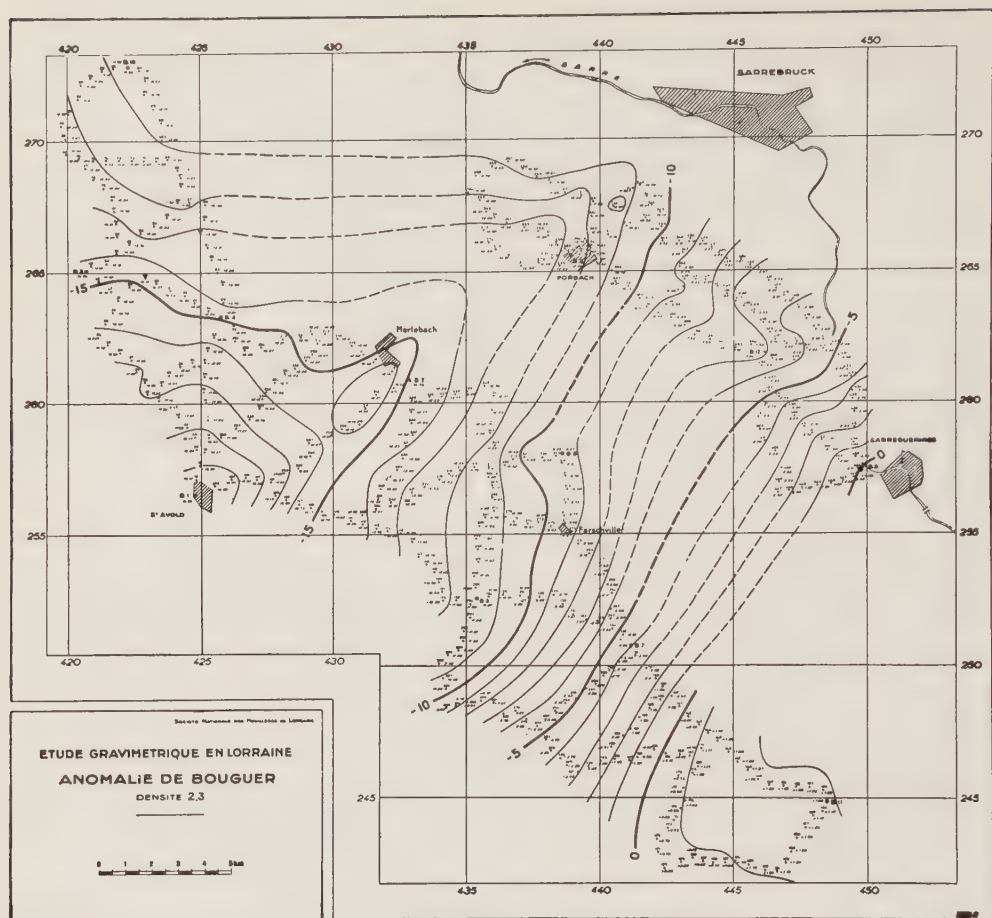
Enfin, il ne reste qu'à calculer l'anomalie régionale en procédant de la même façon :

$$\begin{aligned} R_{21} &= R_{11} + B_{11} & R_{12} &= R_{11} + A_{11} \\ R_{22} &= R_{21} + A_{21} = R_{12} + B_{12} \end{aligned}$$

et ainsi de suite. Un très grand nombre de vérifications sont possibles.

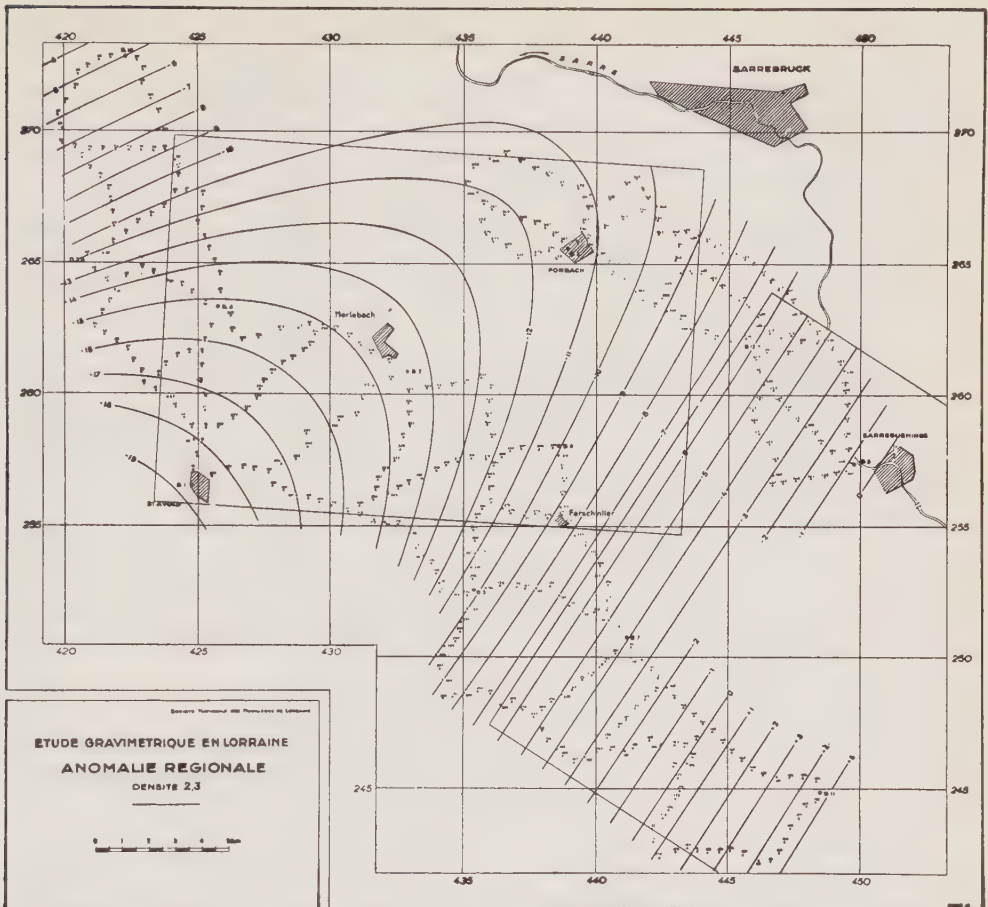
Après avoir rempli toutes les cases on reporte les valeurs de R sur le réseau de la Fig. 3 et on trace les isogammes. Un calculateur peut faire ce calcul en deux jours.

Un premier exemple d'application de la méthode analytique, que je vous prie maintenant d'examiner, n'est pas à proprement parler une véritable prospection gravimétrique. C'est une étude préliminaire à une prospection (qui a d'ailleurs été faite effectivement plus tard).



Carte No. 2.

Avant de commencer une étude systématique de la région, on a voulu s'assurer de l'efficacité de la méthode gravimétrique et surtout être sûr que la gravimétrie puisse surmonter certaines difficultés particulières. La région se trouve en plein dans le houiller du Bassin de Lorraine représenté schématiquement sur la carte n° 1. Elle montre que les terrains stéphanien et westphalien reposent sur un substratum dévonien et cristallin dont la constitution exacte n'est pas bien connue. Dans la partie Nord-Est les terrains carbonifères sont à nu ; plus au Sud, ils sont recouverts de grès vosgiens triasiques. Leur épaisseur croît au fur et à mesure qu'on s'éloigne dans la direction du Sud-Ouest. Le Carbonifère est affecté de plissements formant des anticlinaux dont quatre sont assez bien connus dans la région où cette formation affleure ; sous la couverture triasique par contre le tracé de leurs axes devient plus incertain.

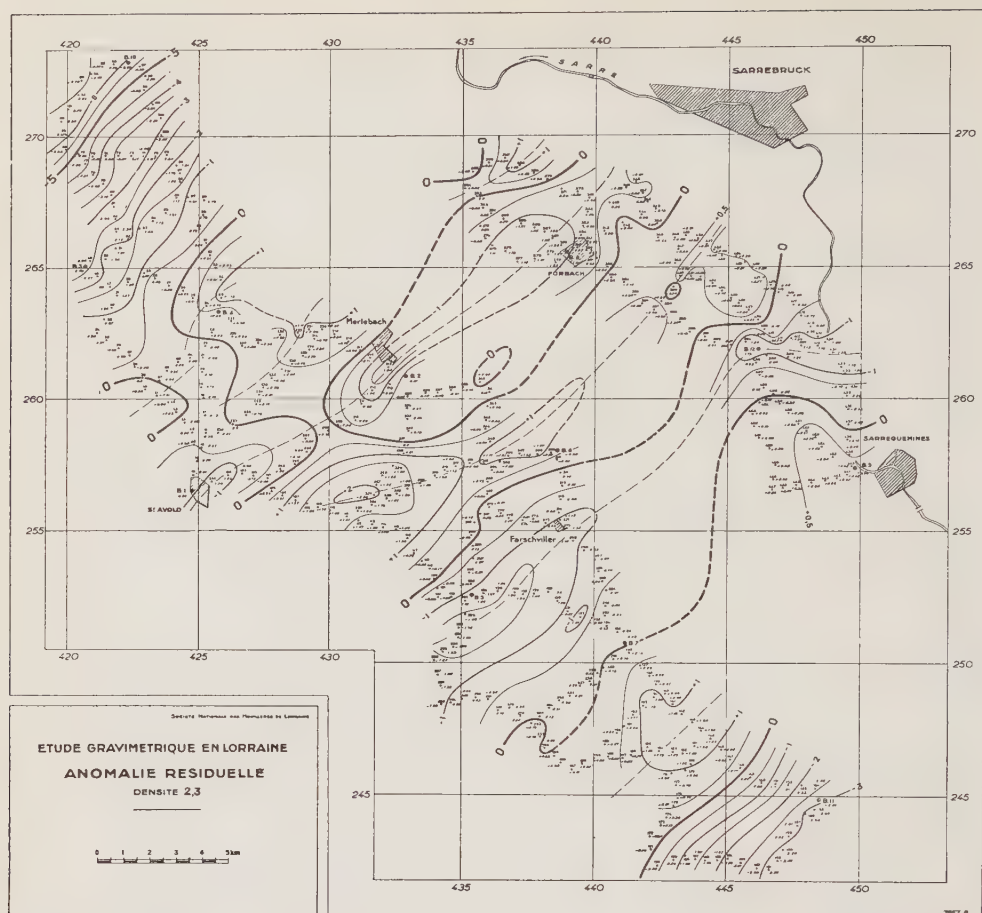


Carte No. 3.

Ainsi donc, trois causes principales pouvaient déterminer les anomalies gravimétriques : l'allure du socle, les variations de l'épaisseur de la couverture et les plissements du Carbonifère.

Il fallait voir si la gravimétrie est capable de fournir un tableau suffisamment net, pour qu'on puisse distinguer entre ces trois causes d'anomalies. En particulier, pouvait-on construire une anomalie résiduelle de façon que les plissements du Carbonifère soient nettement visibles. C'est dans ce but très limité que ce petit essai a été entrepris.

La carte n° 2 montre les résultats de quelques 460 stations réparties en deux groupes allongés perpendiculairement à l'axe structural. Les stations manquent au centre et le tracé des isogammes γ est moins certain, mais ailleurs l'anomalie

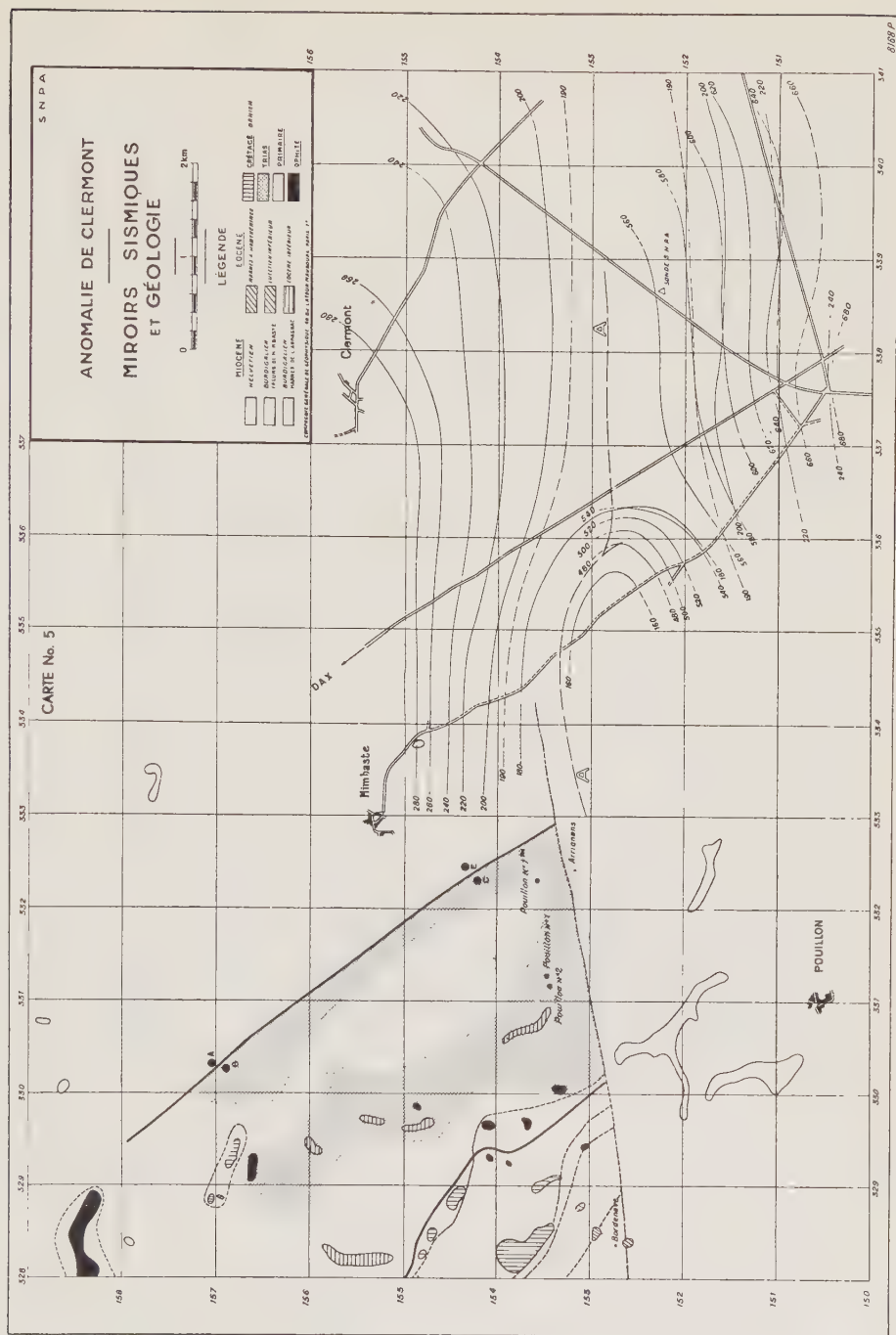


Carte no. 4.

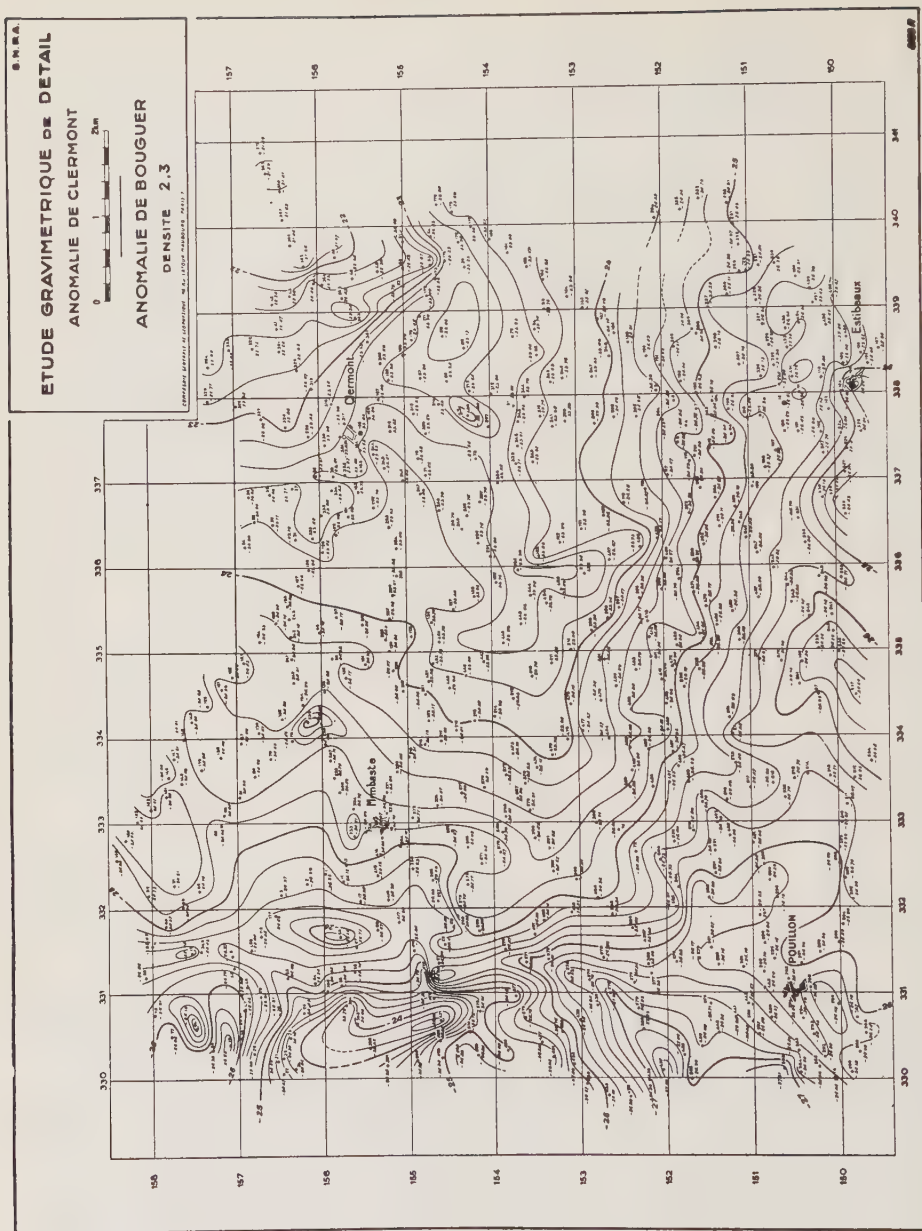
de Bouguer est bien définie. L'influence des plissements du Carbonifère n'est pas du tout visible à première vue.

Il est assez difficile d'imaginer un moyen pour dégager leur influence tout en restant aussi objectif que possible. Nous avons eu recours à la méthode analytique.

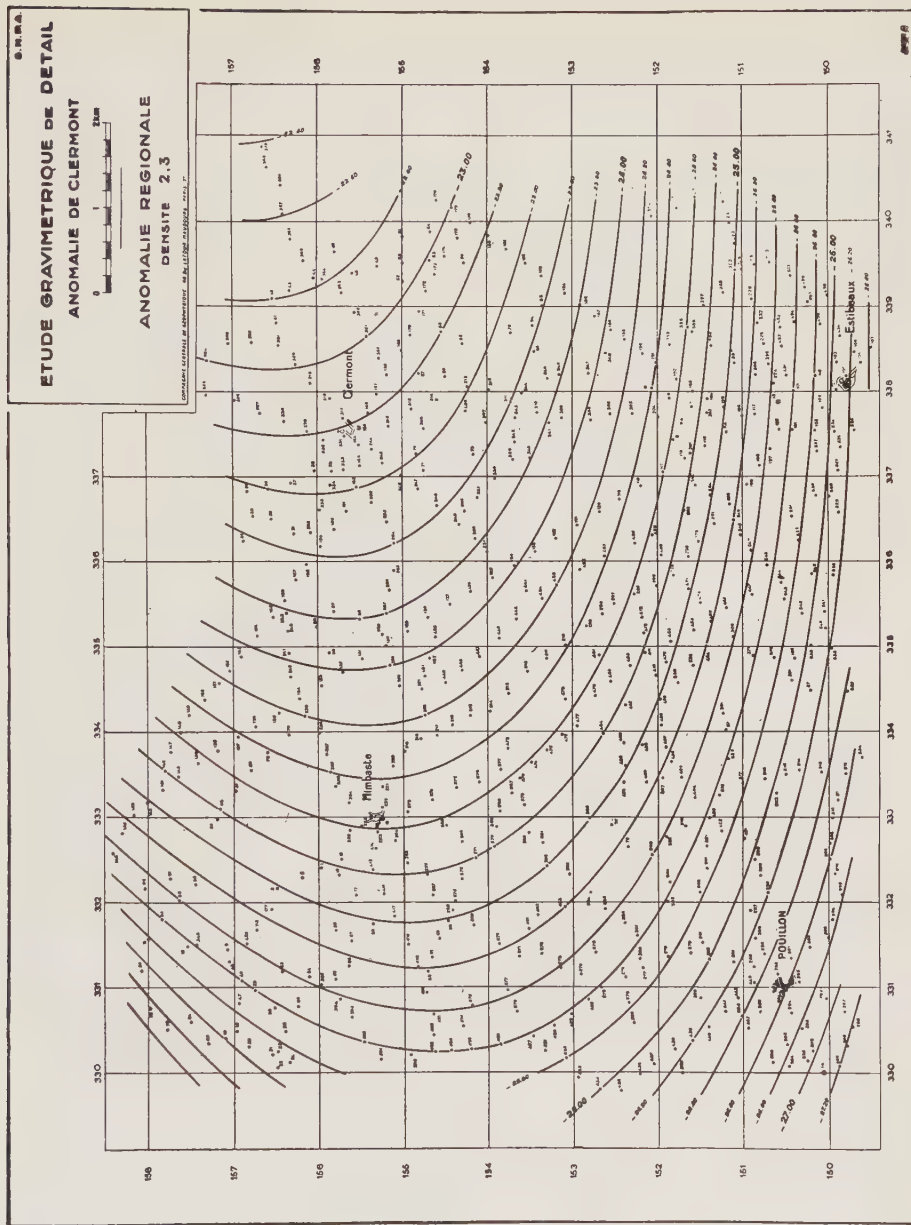
La carte n° 3 montre l'anomalie régionale que nous avons établie. Comme la région est peu étendue, nous nous sommes limités aux termes du 2^e degré. Dans la partie centrale, l'anomalie régionale est donc un simple paraboloïde; son rectangle de définition est indiqué sur la carte. Dans la partie Sud-Est, nous avons assimilé l'anomalie régionale à un plan incliné qui se raccorde d'ailleurs parfaitement au paraboloïde. On ne peut nier que cette anomalie remplit toutes les conditions désirables: elle est très régulière, étendue et objective. De plus,



Carte no. 5.



Carte No. 6.



Carte No. 7.

elle est logique : elle s'explique bien par l'action du socle lourd et par l'accroissement de l'épaisseur des terrains triasiques moins denses que le Carbonifère.

Nous avons relevé la valeur de l'anomalie régionale sur la carte n° 3 pour chaque station effectivement faite sur le terrain, et nous avons construit l'anomalie résiduelle (Carte n° 4). Un simple coup d'œil suffit pour se rendre compte que la direction générale des plissements apparaît très clairement sur la résiduelle. Il faut bien se garder d'en tirer d'autres conclusions, car ce n'est qu'un essai en vue d'une prospection ultérieure. J'ajouterai seulement à l'intention de ceux qui voudraient comparer cette résiduelle avec la carte géologique, que la densité du Stéphanien est probablement un peu plus élevé que celle du Westphalien.

Le second exemple que je vous présente maintenant concerne, comme le premier, une petite étude qui ne couvre que 75 Km carrés environ, mais une étude très détaillée. A l'opposé de notre premier exemple, c'est une étude de complément. Une prospection gravimétrique systématique a été déjà faite auparavant, suivie d'une étude par la méthode sismique.

La carte n° 5 résume quelques données géologiques, peu nombreuses d'ailleurs dans la partie Est de cette région, ainsi que les résultats acquis par la sismique. C'est précisément dans la partie Est que l'étude sismique a abouti au tracé de deux réseaux de courbes isochrones correspondant à deux horizons de profondeurs différentes. Ces courbes dessinent la terminaison orientale d'une structure anticlinale dont l'axe est très bien défini et a une direction Est-Ouest.

A l'Est la géologie, confirmée d'ailleurs par la gravimétrie, montre l'existence d'un accident triasique — (accident de Tercis). Les renseignements fournis par la sismique sont malheureusement insuffisants pour affirmer la continuité entre la structure découverte par la sismique et l'accident de Tercis : l'absence de réflexions dans la zone Ouest n'a pas permis de résoudre complètement le problème.

C'est alors qu'on a décidé de recourir de nouveau à la gravimétrie dans l'espoir qu'une étude détaillée puisse fournir quelques renseignements supplémentaires.

L'anomalie de Bouguer expérimentale est montrée sur la carte n° 6. Elle est assez faible, mais affectée de nombreuses irrégularités très localisées.

L'anomalie régionale a été construite par la méthode analytique (Carte n° 7) et n'appelle aucune remarque spéciale.

Enfin, la carte n° 8 montre l'anomalie résiduelle obtenue par différence. L'axe gravimétrique coïncide bien avec l'axe de la structure découverte par la sismique. Cette dernière apparaît comme une structure fermée et se sépare nettement de l'accident triasique de Tercis.

J'exprime ma reconnaissance à la Direction des Houillères du Bassin de Lorraine et à la Société Nationale des Pétroles d'Aquitaine pour la permission de publier ces résultats. Tous les calculs nécessités par la mise au point de la méthode analytique ont été effectués dans les laboratoires de la Compagnie Générale de Géophysique à laquelle j'adresse également mes remerciements.

ANNEXE — Coefficients numériques pour le calcul des C_{mn} $10^5 C_{00}$

—1369	—1760	—613	+164	—613	—1760	—1369
—1760	—1217	+2190	+4204	+2190	—1217	—1760
—613	+2190	+8258	+11501	+8258	+2190	—613
+164	+4204	+11501	+15285	+11501	+4204	+164
—1760	—1217	+2190	+4204	+2190	—1217	—1760
—1369	—1760	—613	+164	—613	—1760	—1369

 $10^5 C_{10}$

+4470	+1395	—4031	0	+4031	—1395	—4470
+6311	—2726	—13013	0	+13013	+2726	—6311
+3525	—12296	—24128	0	+24128	+12296	—3525
+1481	—17468	—29419	0	+29419	+17468	—1481
+3525	—12296	—24128	0	+24128	+12296	—3525
+6311	—2726	—13013	0	+13013	+2726	—6311
+4470	+1395	—4031	0	+4031	—1395	—4470

 $10^5 C_{01}$

—4470	—6311	—3525	—1481	—3525	—6311	—4470
—1395	+2726	+12296	+17468	+12296	+2726	—1395
+4031	+13013	+24128	+29419	+24128	+13013	+4031
0	0	0	0	0	0	0
—4031	—13013	—24128	—29419	—24128	—13013	—4031
+1395	—2726	—12296	—17468	—12296	—2726	+1395
+4470	+6311	+3525	+1481	+3525	+6311	+4470

 $10^5 C_{20}$

+2681	+2209	—2340	—5074	—2340	+2209	+2681
+5786	+4759	—5063	—10961	—5063	+4759	+5786
+7886	+6503	—6919	—14963	—6919	+6503	+7886
+8640	+7118	—7571	—16376	—7571	+7118	+8640
+7886	+6503	—6919	—14963	—6919	+6503	+7886
+5786	+4759	—5063	—10961	—5063	+4759	+5786
+2681	+2209	—2340	—5074	—2340	+2209	+2681

 $10^5 C_{11}$

—3402	—5733	—4284	0	+4284	+5733	+3402
—5733	—9675	—7236	0	+7236	+9675	+5733
—4284	—7236	—5400	0	+5400	+7236	+4284
0	0	0	0	0	0	0
+4284	+7236	+5400	0	—5400	—7236	—4284
+5733	+9675	+7236	0	—7236	—9675	—5733
+3402	+5733	+4284	0	—4284	—5733	—3402

$10^5 C_{02}$

+2681	+5786	+7886	+8640	+7886	+5786	+2681
+2209	+4759	+6503	+7118	+6503	+4759	+2209
-2340	-5063	-6919	-7571	-6919	-5063	-2340
-5074	-10961	-14963	-16376	-14963	-10961	-5074
-2340	-5063	-6919	-7571	-6919	-5063	-2340
+2209	+4759	+6503	+7118	+6503	+4759	+2209
+2681	+5786	+7886	+8640	+7886	+5786	+2681

 $10^5 C_{30}$

-5215	+1470	+9546	0	-9546	-1470	+5215
-11314	+3194	+20668	0	-20668	-3194	+11314
-15453	+4331	+28149	0	-28149	-4331	+15453
-16914	+4734	+30818	0	-30818	-4734	+16914
-15453	+4331	+28149	0	-28149	-4331	+15453
-11314	+3194	+20668	0	-20668	-3194	+11314
-5215	+1470	+9546	0	-9546	-1470	+5215

 $10^5 C_{21}$

+7605	+6300	-6683	-14445	-6683	+6300	+7605
+12870	+10620	-11273	-24379	-11273	+10620	+12870
+9608	+7920	-8404	-18214	-8404	+7920	+9608
0	0	0	0	0	0	0
-9608	-7920	+8404	+18214	+8404	-7920	-9608
-12870	-10620	+11273	+24379	+11273	-10620	-12870
-7605	-6300	+6683	+14445	+6683	-6300	-7605

 $10^5 C_{12}$

-7605	-12870	-9608	0	+9608	+12870	+7605
-6300	-10620	-7920	0	+7920	+10620	+6300
+6683	+11273	+8404	0	-8404	-11273	-6683
+14445	+24379	+18214	0	-18214	-24379	-14445
+6683	+11273	+8404	0	-8404	-11273	-6683
-6300	-10620	-7920	0	+7920	+10620	+6300
-7605	-12870	-9608	0	+9608	+12870	+7605

 $10^5 C_{03}$

+5215	+11314	+15453	+16914	+15453	+11314	+5215
-1470	-3194	-1331	-4734	-4331	-3194	-1470
-9546	-20668	-28149	-30818	-28149	-20668	-9546
0	0	0	0	0	0	0
+9546	+20668	+28149	+30818	+28149	+20668	+9546
+1470	+3194	+4331	+4734	+4331	+3194	+1470
-5215	-11314	-15453	-16914	-15453	-11314	-5215

DISCUSSION

Mr. BRUCKSHAW: The condition assumed for the separation of the regional and local anomaly seems to imply that the latter is a random distribution superimposed upon the former. Conditions can be visualised as, for example, in a

region where saltdomes produce systematic negative anomalies, when this condition would not be satisfied.

Mr. BARANOV: Indeed, in the case mentioned by Mr. Bruckshaw the anomaly calculated with the analytic method will differ with a constant of the real anomaly, but I do not think that this difference will be of much importance.

Mr. ROSENBACH: The regional anomaly for the rectangular area of map No. 3 has been calculated as a surface of the second degree. Has the regional anomaly also been calculated as a surface of the third degree, thus making a comparison possible between the residual anomaly in this last mentioned case and map No. 4?

Mr. BARANOV: No, such a calculation has not been made.

Mr. SCHLEUSENER: A regional anomaly can be defined as one much larger than the anomaly we are looking for. In the case of a salt dome, the regional anomaly should cover at least 10 kms. If we are looking for still greater objects the scale of the regional anomaly will be greater still. No clear mathematical definition of the regional anomaly is possible.

Mr. BARANOV: I agree.

HYDROLOGICAL SURVEYS IN THE CATANIA AREA BY MEANS OF ELECTRICAL SOUNDINGS *

BY

J. J. BREUSSE ** AND G. HUOT **

ABSTRACT

Exploration of the Catania region was carried out for over a year by means of electrical soundings. The thickness of the overburden (lava and alluvium) was thus computed and the contour map of the blue clays basement shows the existence of several buried channels where new wells were drilled, all of them successful.

In December 1952 an hydrological survey of the Etna piedmont was begun by electrical prospecting. This survey, extending all around the periphery of this important volcanic system, has been continued for over a year. We are presenting below the results recorded on the Southern flank of the Etna, in the Catania and Paterno areas, where the exploration started.

A few words might be said about the geological conditions encountered (fig. 1). The basement is constituted by plastic blue clays of ancient Quaternary, Sicilian stage. These clays outcrop over a wide area South-East from Misterbianco and from place to place in the neighbourhood of Paterno and Catania (see four small outcrops on map of fig. 1).

The overburden is constituted by lava in the Northern part: E zone, and by alluvium in the Southern part: A, B and C zones. The alluvium is generally made of coarse elements in B and C zones where it created terraces. In the Catania plain, coarse deposits, sands and gravels, are found, but these deposits are concealed by a layer of clayey silt.

All these formations have been explored by means of numerous private wells and by drilling. However numerous expensive works remained dry or nearly so, such as holes no. 30 C, 31 C, 32 C and 7. This can be explained by the fact that the best location cannot be selected rationally with the only help of surface geology. It was thus necessary to study systematically the subsurface conditions by means of electrical soundings. Three distinct problems had to be investigated.

1° — *Topography of the top of blue clays*

Obviously infiltration waters are mainly collected by the depressions of the impermeable basement.

2° — *Water-bearing possibilities of sandy beds interstratified in the clays*

* Presented at the Milan Meeting of the European Association of Exploration Geophysicists, December 2/4, 1953.

** Compagnie Générale de Géophysique, Paris.

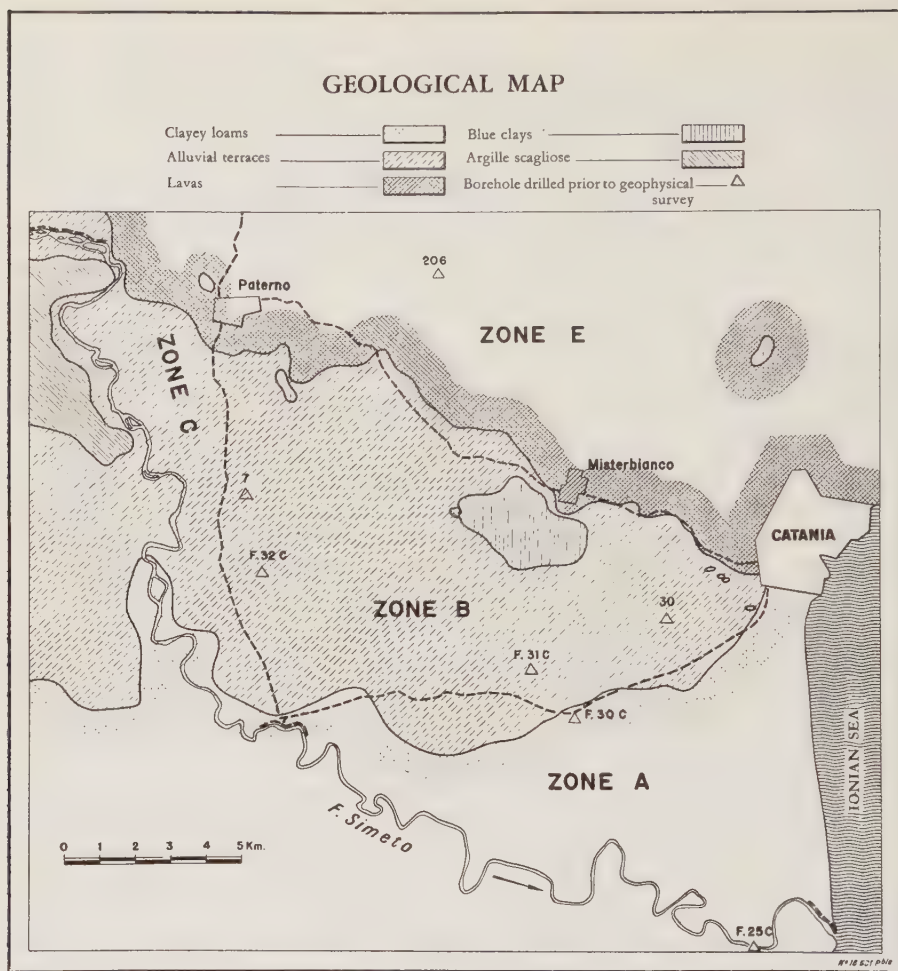


Fig. 1.

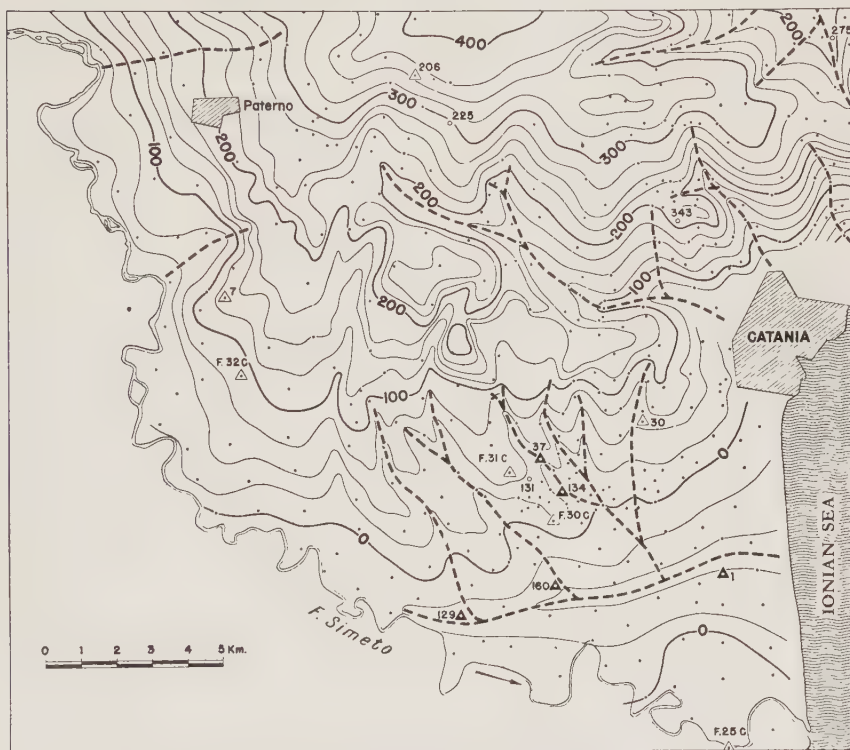
Several wells or boreholes encountered sandy lenses inside the Sicilian complex. As a rule the output is low and the water is brackish, however it may sometimes be used.

3° — Possibilities of the Tertiary underlaying the Quaternary series

No Tertiary outcrops have been found in the area surveyed, however it has been encountered at 100 m. depth, in hole 25 C, in the Southern limit of A zone. This Tertiary is composed of conchitic sands and limestones as well as of basalts and volcanic breccia originated in the Lentini eruptive system, located Southwards. Several drillings have been made at greater depth, in order to attempt

CONTOUR MAP OF THE BLUE CLAYS

Electrical logging site ————— • Borehole drilled prior to geophysical survey ———— Δ
 Contour and height of roof of blue clays ———— 100 Borehole drilled in accordance with results of ———— Δ
 Approximate axis of fossil valley ———— geophysical survey



EXAMPLES OF ELECTRICAL LOGS

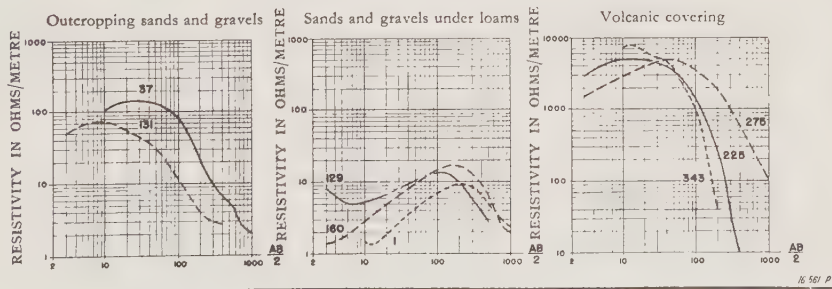


Fig. 2.

to find it again under A and B zones, but these attempts were unsuccessful. Hole 30 C was stopped at 275 m., still in blue clays.

From the beginning of the survey through a small number of E.S. using a very long output line ($AB = 2,000$ to $3,000$ m.) and distributed over the whole area, it has been possible to recommend to give up definitively deep exploration into the Sicilian complex and into the underlying Tertiary. Electrical soundings encounter generally under the alluvial or volcanic resistant overburden, a tremendous thickness (more than 500 m.) of an evenly conductive formation of $2-3$ ohms m., evidencing that the blue clay thickness is considerably greater than was assumed.

As regards the eventual sandy beds inter-stratified in this impermeable series, they do not appear on the diagrams. It is thus possible to state that they exist everywhere either in very thin layers or impregnated with salt water, and therefore they do not deserve further study.

Accordingly only alluvium and lava possibilities should be considered and this hydrological survey comes down to establishing a contour map of the top of the clays (fig. 2). Before describing this map, the main types of electrical soundings may be considered. Though permeable formations be noticeably more resistant than their blue clay substratum, the quantitative interpretation of diagrams is not always quite easy.

These interpretations are comparatively simple in the case of outcropping sands and gravels where one has to deal with two layers diagrams (see E.S. 37 and 131). On the contrary these interpretations are more difficult in the case of "bell shaped" curves, corresponding to the following series: silts, gravels, clays, which is normally encountered in the Catania plain (see E.S. 129, 160 and 1). Finally, when operating on zones with highly resistant volcanic overburden, the curves plotted are similar to E.S. made with two layers but several horizons, the resistivity of which varies from several hundreds ohms m. to about 10 ohms m. (alluvium, altered lava) can be comprised between compact lava of several thousands ohms m. and a clayey basement of $2-3$ ohms m., without appearing on the diagrams (see E.S. 343 and 225).

These intermediate strata are revealed by an abnormal slope of the descending curve of the diagram (E.S. 275) only if they are thick enough. As a matter of fact in the areas covered by lava it cannot be expected to determine accurately the depths to blue clays. However experience has shown that the most important features of the clays topography can be determined and as regards hydrology this is the main point.

These remarks being made, the clay contour map shows the following results. The clayey mass culminates North-East of Paterno and its flanks, sloping down gently to the Simeto River and to the sea, have been cut by an important ancient hydrographical network. It is obvious that lava waters flow down mainly in the direction of Catania and in a North-North-East direction. A less important part is directed to the Simeto River through an East-West ancient valley located North of Paterno.

As regards the Southern area constituted by alluvial terraces and by the Catania plain, this area can be considered as an autonomous basin. As a matter of fact an argillaceous ridge extends from Paterno to Catania. Electrical soundings revealed that this impervious mole is generally outcropping or very shallow and cannot be crossed by lava waters. The sole external contribution received by the Catania plain is thus the infra-flow of the Simeto, the old bed of which is quite evident North of the present river-bed. Three fossil thalwegs, located near the present streams but considerably deeper, emerge into this buried channel.

All the fundamental data covering the underground hydrography of a wide area of more than 300 sq.km. were thus obtained in six months by means of 400 electrical soundings.

Check drillings have been started without delay. The first boreholes have been located over alluvial terraces and in the Catania plain. Five wells have been already completed on E.S. 134, 160, 37, 129, 1, and all of them were successful. Drilling at E.S. 1 gave 10 l/sec. on tests but it is not sure that this drilling was deep enough. Drillings 134 and 37 gave 8 and 9 l/sec., respectively. This is interesting if the relatively high surface elevation of these soundings and the neighbourhood of two dry wells (30 C and 31 C) anterior to this geophysical survey are considered. Finally at drillings 129 and 160, important artesian water sheets have been encountered. It would not be possible to better illustrate the efficiency of electrical methods applied to this kind of problems.

A TEST ON ELASTIC ANISOTROPY MEASUREMENT AT BERRIANE (North Sahara) *

BY

JACQUES CHOLET ** & HENRI RICHARD ***

ABSTRACT

The geophysicists who attempted to evaluate elastic anisotropy of some bedded formations most often gave but little information about recording and interpreting the measurements.

May be they did not lay enough stress on the fact that any determination of the anisotropy factor is a critical operation and that, to have some certainty, it must be made under good conditions and then discussed.

Due to the very favourable conditions offered: undisturbed tectonics and topography, relatively regular series the Berriane district in Northern Sahara, is rather well suited to accurate measurements and to an anisotropy study down to 1,250 meters. Since measurements have been carried out in the wildcat drilled at Berriane by S. N. Repal, it seems interesting to communicate the results obtained and to discuss them according to the influence of high velocity layers.

It can be noted that in the clay and sand series which have been investigated, anisotropy coefficient amounts to 1.09 or so.

To conclude, it seems desirable that determinations made by numerous operators should allow a more accurate knowledge of the anisotropy factor in the main types of rocks.

The geophysicists who attempted to evaluate elastic anisotropy of some bedded formations most often gave but little information about recording and interpreting the measurements. They noted that, as a rule, velocities are higher following the strata than perpendicularly to them. But, may be, they did not lay enough stress on the fact that any determination of the anisotropy factor is a critical operation and that, to have some certainty, it must be made under good conditions and then discussed. Otherwise, there are chances to ascribe partially to anisotropy an apparent velocity change caused by other factors (we shall not deal here of the phenomena studied in laboratory, on samples, but of those actually encountered in seismic surveys: layers having a thickness varying from about ten to several hundreds of metres, wave lengths of 10 metres or even more).

In the present state of our personal knowledge, it seems wise to restrict us to the simple diagram shown in fig. 1, which yet, we are sure, will bring in difficulties.

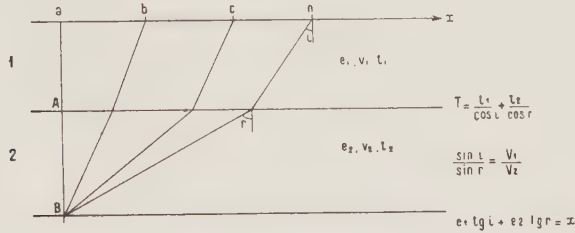
* Presented at the Milan meeting of the European Association of Exploration Geophysicists, 2/4 Dec. 1953.

** Société Nationale de Recherches du Pétrole en Algérie.

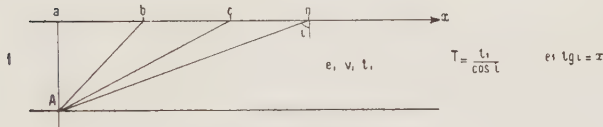
*** Compagnie Générale de Géophysique.

Let us consider, under an horizontal surface, two homogeneous layers, 1 & 2, separated by a horizontal plane. If a deep drilling is available, let us measure the travel time T between shot points $a, b \dots n$ at distances x and a seismograph lowered in A , then in B (fig. 1).

$$\text{Let } e_1, V_1, t_1 \\ e_2, V_2, t_2$$



Basis diagram.



Study of the first layer.

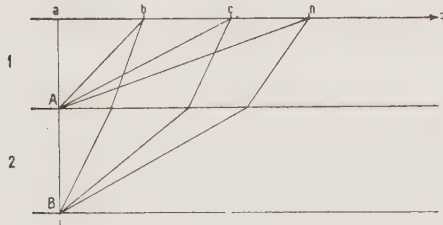


Fig. 1. Study of the two layer.

be the thicknesses, vertical velocities and vertical travel times in each layer.

When the layers are isotropic, the travel time on path An shall be:

$$(1) \quad T = \frac{t_1}{\cos i}$$

$$\text{with: } e_1 \operatorname{tg} i = x.$$

On path Bn

$$(2) \quad T = \frac{t_1}{\cos i} + \frac{t_2}{\cos r}$$

$$\text{with } \begin{cases} \frac{\sin r}{\sin i} = \frac{V_1}{V_2} \\ e_1 \operatorname{tg} i + e_2 \operatorname{tg} r = x \end{cases}$$

Let us suppose that the layers are uniaxial anisotropic mediums with vertical axis *and same anisotropy factor* K . The travel times calculated according to (1) & (2) do not correspond any longer to a point of abscissa x but to a point of abscissa Kx . In the present case, it is known that the rays and wave fronts are derived from those of the isotropic case by a simple dilatation around the axis.

Thus, in order to find out K , it is enough to compare the experimental values of T with the values computed from above equations system; the calculations can be extended to cover the cases of more than two layers.

The most probable K factor is the one giving the values closer to the experimental times.

Unfortunately several important error sources are to be feared.

Effects of surface heterogeneities and of topography

When superficial corrections are too important, they involve approximations of several milliseconds on travel times.

Dips

If stratification is not strictly horizontal it is necessary to carry out corrections more doubtful as the measurements are taken on thicker beds.

Velocity increase according to depth

If this velocity increase is important the pathes curvature becomes stronger moving away from a , and this fact combined to anisotropy gives more and more precarious interpretations.

Heterogeneities in the layers studied

Evidently, the layers must be as homogeneous as possible on their whole thickness. This condition seems the most difficult one to meet. At the scale considered, layers will often be found giving the same results as an homogeneous formation, even when dealing with complexes such as clay and sand or limestone and marl etc.; but it happens frequently that thin intercalations having a very high velocity: hard limestone, dolomite, anhydrite, salt beds ... alter measurement interpretation. When the pathes become very oblique, path components inside these beds have a relatively increasing importance. Apparent velocity is thus increased and this increase is wrongly attributed to an anisotropic effect. This error (the most important one) is the most common and the most difficult to avoid. It is allowed to think that it may have been made by several seismologists.

In spite of the fact that ideal formations do not exist in nature, it is however possible to find out areas where experimental conditions are especially favourable, for instance the district of Berriane well in northern Sahara.

This district has the privilege to have a gentle topography and surface corrections are very small: a few milliseconds.

Stratification can be considered as strictly horizontal. The dips which have

been accurately studied by refraction shooting down to 1,250 m are smaller than 1 degree.

Last, depth has very little effect on velocity.

Though lithological conditions reported hereunder are not so uncommon, this district is however very favourable to trying elastic anisotropy factor measurements down to a rather important depth.

These measurements have been attempted because it was possible to derive from them a correction when determining the depths of refraction markers.

It seemed interesting to set forth here the main conditions and the results: geological cross section, vertical velocities from 0 to 1,250 m.

measurement of travel times.

interpretation, discussion.

GEOLOGICAL CROSS SECTION — VERTICAL VELOCITIES

The hole log is:

0-80 m: Turonian, hard limestones and soft chalky limestones alternating.

80 to 310 m: Cenomanian. Slightly sandy clays with some thin anhydrite and limestone beds.

310 to 1,225 m: Continental insertion. Clay and sand complex, sometimes marly, with several anhydrite or limestone intercalations. Sand rate falls down to a very low value below 800 metres.

1,225-1250 m: Top of Jurassic, clays, marls, limestones.

Actually the lithological scale can be divided into two sections:

0 to 800 metres	{	700 metres approx. of sand and clay complex
		50 metres approx. of soft chalky limestone
		50 metres approx. limestones and anhydrite
800 to 1,250 m	}	Clay with a very little sand (practically no limestone)

Vertical velocity measurements in the well show a very small variation with depth. This fact allows the two following approximations:

In the first approximation, two beds of uniform velocity are differentiated:

from 0 to 800 metres. Vertical travel time: 322 milliseconds. $V = 2,485$ metres per second.

from 800 to 1,250 m. Vertical travel time: 156 milliseconds. $V = 2,890$ metres per second.

In the second approximation

Instead of two layers, an hypothesis closer to reality is a linear increase of velocity with depth according to formula

$V = 2,250 + 0,6 P$ (where P is the depth expressed in metres). The following table will show the recorded travel times, the computed travel times and the differences (very small anyhow):

P	Recorded vertical time	Computed time, $V = 2,250 + 0.6 P$	Computed time, 2 layers with uniform velocities $V = 2,485$; $V = 2,890$
310	136	131 (-5)	124 (-12)
485	204	202 (-2)	195 (-9)
670	270	272 (+2)	269 (-1)
800	322	322 (0)	322 (0)
930	369	370 (+1)	367 (-2)
1100	430	428 (-2)	426 (-4)
1250	478	478 (0)	478 (0)

It is to be noted that vertical velocities are comparatively low due to the fact that high velocity beds are too thin to be evidenced by the measurements. We pointed out that the total thickness of these high velocity beds distributed between 0 and 800 metres of depth could be evaluated to 50 metres or so. According to the results of the refraction survey, their horizontal velocity is very close to 4,400 metres per second.

It is thus logical to consider a *third approximation* taking into account the presence of inter-bedded high velocity layers, keeping however the vertical travel times unmodified

from 0 to 800 metres: 750 metres, $V = 2,425$

50 metres, $V = 4,000$

from 800 to 1,250 metres: 450 metres, $V = 2,890$

(it is shown hereunder that the value of the vertical velocity proposed, $V = 4,000$ in the high velocity series, is very satisfactory).

MEASUREMENT OF TRAVEL TIMES

The two complexes: 0-800, 800-1,250 of the lithological scale lead us to carry out measurements in accordance with the diagram shown in fig. 1.

Seismograph in A: $aA = 800$ metres.

Seismograph in B: $aB = 1,250$ metres.

Travel time measurements between the seismograph and the surface have been carried out for $x = 100, 400, 800, 1,200$ and $1,600$ metres. " x " has been taken as distant as possible to make more prominent the influence of anisotropy on the first hand and the influence of high velocity intercalations on the other hand.

Times measured are as follows: (fig. 2).

from 0 to 800 metres.

X	Recorded times	Times corrected to an horizontal reference plane
100	323	323
400	353	354
800	432	433
1,200	522	522
1,600	608	610

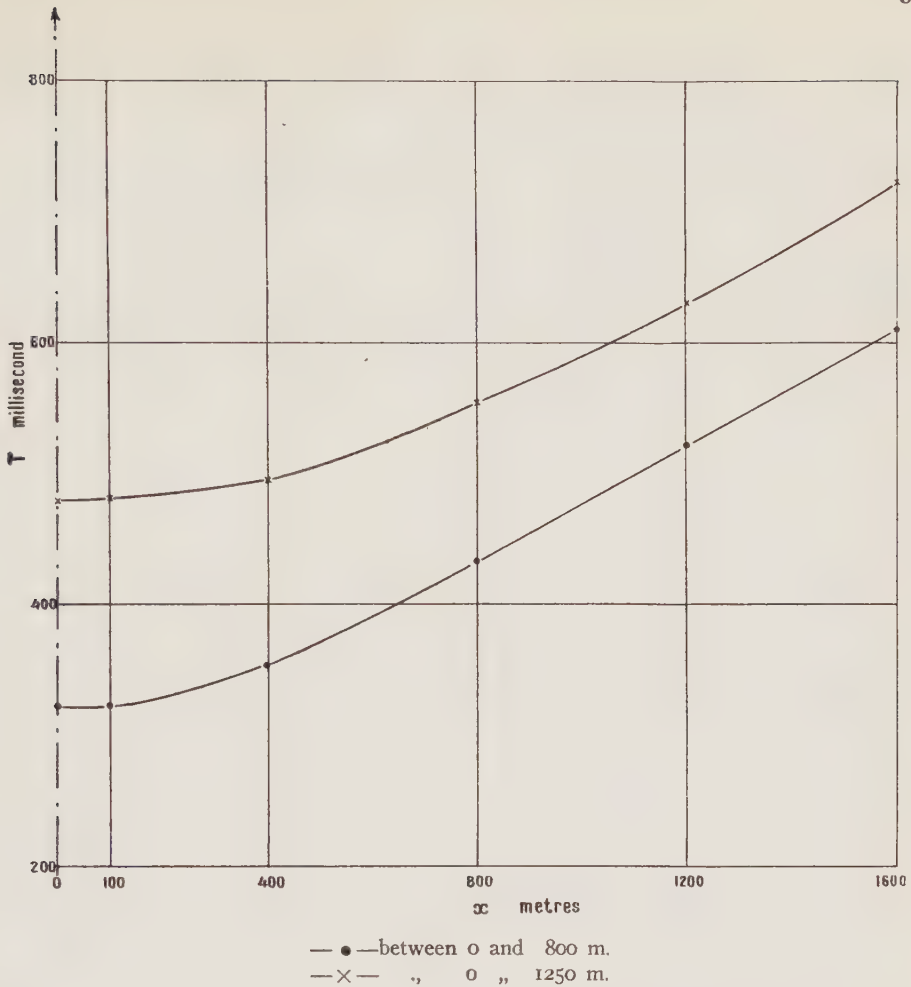


Fig. 2. Recorded times.

from 0 to 1,250 metres.

X	Recorded times	Times corrected to an horizontal reference plane
100	481	481
400	493	495
800	533	555
1,200	636	630
1,600	721	722

Measurements have been made at the South of the well. Some measurements Northwards and Westwards allowed to check that the results were symmetrical with respect to the wildcat.

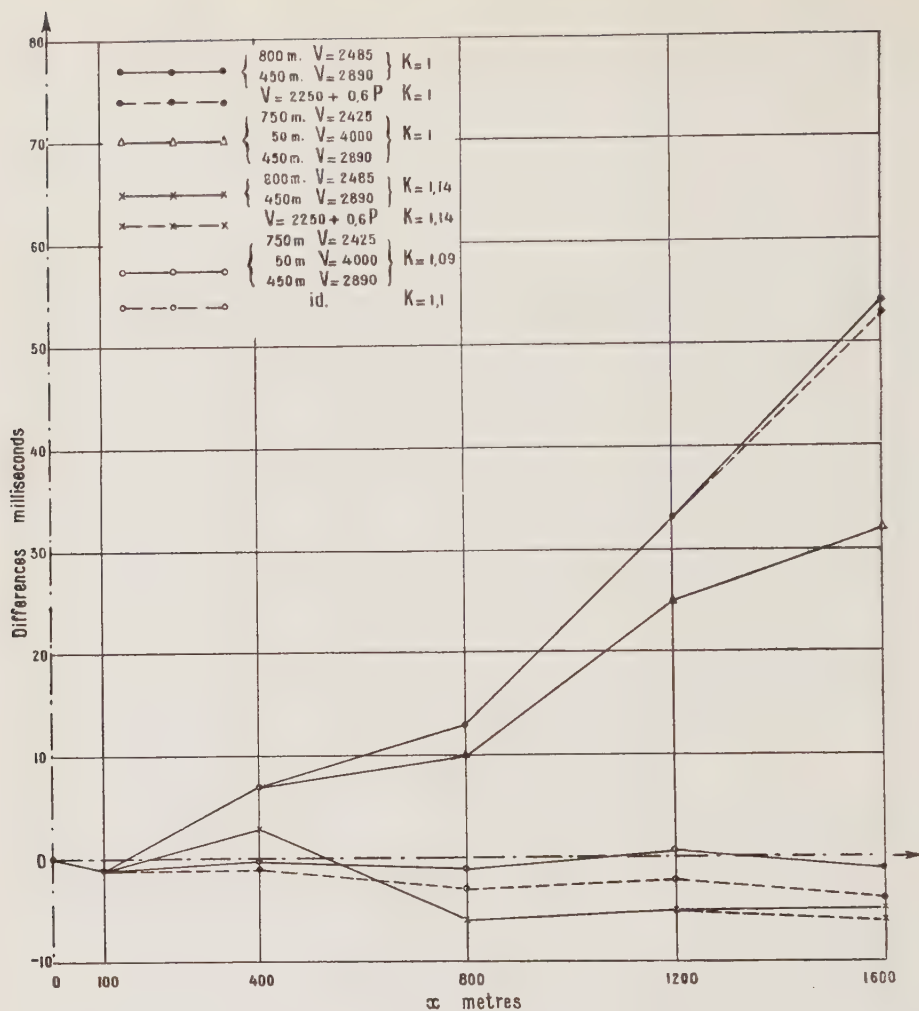


Fig. 3. Differences.

INTERPRETATION

Recorded times must be compared to computed times starting from the three approximations retained.

(A). Between 0 and 800 metres (fig. 3).

First approximation. Uniform velocity

$V = 2,485$ metres per second.

Computed times and their differences with recorded times are:

x	Computed times	Difference
0	322	0
100	324	+ 1
400	361	+ 7
800	456	+ 23
1,200	581	+ 59
1,600	720	+ 110

Due to the high velocity layers and to anisotropy, differences increase rapidly with x .

If we suppose an anisotropy factor $K = 1.14$ and if the computed times are reduced to the values of x which have been considered:

x	Computed time	Difference
0	322	0
100	324	+ 1
400	351	- 3
800	428	- 5
1,200	532	+ 10
1,600	649	+ 39

Thus, introducing anisotropy only, it is possible to make the difference smaller but, beyond 800 metres, computed times increase too rapidly. Using a higher factor would make the difference smaller for high values of x but would make them bigger for the low values.

Second approximation: One layer case with progressively increasing velocity: $V = 2,250 + 0.6 P$.

Computed times are very close to those given in the first approximation, in spite of the velocity of the layers varying from 2,250 to 2,730.

x	Calculated time ($K = 1$)	Difference
0	322	0
100	324	+ 1
400	361	+ 7
800	455	+ 22
1,200	579	+ 57
1,600	717	+ 107

The same holds true if we introduce anisotropy into the calculations.

The velocity increase factor is too small to cause a divergence between the two approximations for the values of x , considered.

Third approximation. 750 metres $V = 2,425$
50 metres $V = 4,000$

Computed times and differences are as follows:

x	Calculated times	Differences
0	322	0
100	324	+ 1
400	359	+ 5
800	447	+ 14
1,200	547	+ 25
1,600	647	+ 37

Differences are too important when x is bigger than 400 metres.

If we suppose an anisotropy factor of 1.09 or 1.10, it comes:

x	Computed times $K = 1.09$	Difference $K = 1.09$	Computed times $K = 1.10$	Difference $K = 1.10$
0	322	0	322	0
100	324	+1	324	+1
400	354	0	354	0
800	432	-1	430	-3
1,200	522	0	520	-2
1,600	612	+2	609	+1

Taking into account the high velocity layers and an anisotropy factor of 1.09, differences are negligible.

The various results are grouped in a table and on the graph of fig. 3.

Differences between computed times and recorded times from 0 to 800 metres.

X	$V = 2485$		$V = 2250 + 0,6P$		750 metres $V = 2425$ 50 metres $V = 4000$		
	$K = 1$	$K = 1.14$	$K = 1$	$K = 1.14$	$k = 1$	$k = 1.09$	$K = 1.1$
0	0	0	0	0	0	0	0
100	+ 1	+ 1	+ 1	+ 1	+ 1	+1	+1
400	+ 7	- 3	+ 7	- 3	+ 5	0	0
800	+ 23	- 5	+ 22	- 6	+14	-1	-3
1200	+ 59	+10	+ 57	+ 8	+25	0	-2
1600	+110	+39	+107	+36	+37	+2	+1

(B). *Between 0 and 1,250 metres (fig. 4).*

First approximation case of two uniform velocity layers:

800 metres, $V = 2,485$

450 metres, $V = 2,890$

Computed times and differences with respect to recorded times are as follows, assuming $K = 1$ and $K = 1.14$.

x	Computed times $k = 1$	Differences $k = 1$	Computed times $K = 1.14$	Differences $K = 1.14$
0	478	0	478	0
100	480	- 1	480	-1
400	502	+ 7	498	+3
800	568	+13	549	-6
1,200	663	+33	625	-5
1,600	776	+54	716	-6

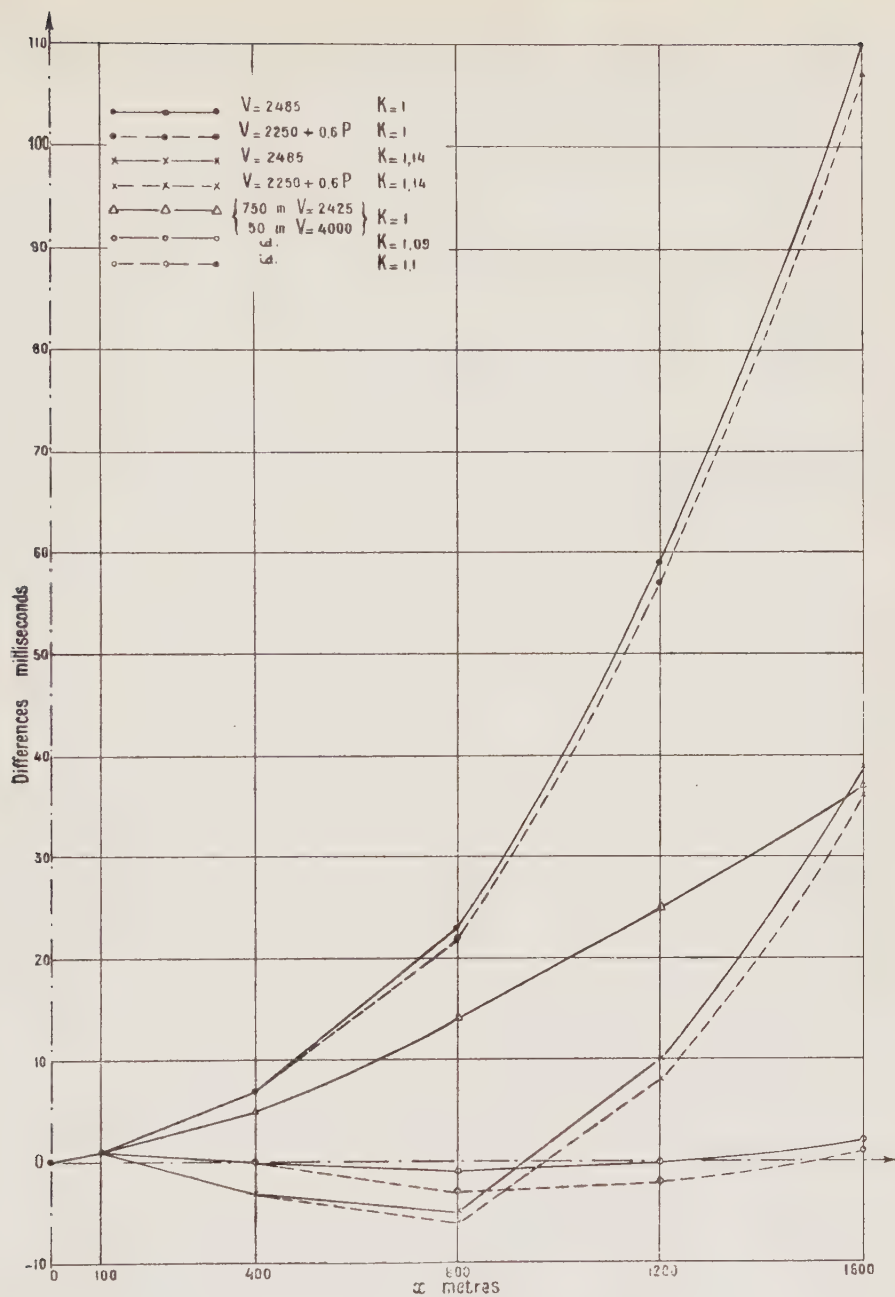


Fig. 4. Differences.

Anisotropy factor 1.14 brings in an important correction but gives too high a value for $x = 400$ and too low beyond.

Second approximation

One layer case with a progressively increasing velocity.

$$V = 2,250 + 0,6 P$$

Computed times are those given by the first approximation within 1 milli-second though velocity varies from 2,250 to 3,000.

Third approximation

$$750 \text{ metres, } V = 2,425$$

$$50 \text{ metres, } V = 4,000$$

$$450 \text{ metres, } V = 2,890$$

Computed times and differences are:

x	Computed times $K = 1$	Differ- ences $K = 1$	Computed times $K = 1.09$	Differ- ences $K = 1.09$	Computed times $K = 1.10$	Differ- ences $K = 1.1$
0	478	0	478	0	478	0
100	480	-1	480	-1	480	-1
400	502	+7	495	0	494	-1
800	565	+10	554	-1	552	-3
1200	655	+25	631	+1	628	-2
1600	754	+32	721	-1	718	-4

As in the case of the upper series between 0 and 800 metres we can conclude that the third approximation, combined with an anisotropy factor of 1.09 or so, is very near the mark.

The differences are summed up in the following table and on the diagrams of fig. 4.

Differences between computed times and measured times, between 0 and 1,250 metres.

x	800 m $V = 2485$ 450 m $V = 2890$		$V = 2250 + 0.6 P$		750 m $V = 2425$ 50 m $V = 4000$ 450 m $V = 2890$		
	$K = 1$	$K = 1.14$	$K = 1$	$K = 1.14$	$K = 1$	$K = 1.09$	$K = 1.1$
0	0	0	0	0	0	0	0
100	-1	-1	-1	-1	-1	-1	-1
400	+7	+3	+7	+3	+7	0	-1
800	+13	-6	+13	-6	+10	-1	-3
1200	+33	-5	+33	-5	+25	+1	-2
1600	+54	-6	+53	-5	+32	-1	-4

Note: $K = 1.09$ leads to an horizontal velocity of 4,360 in high velocity layers. This value is close to that recorded during the refraction survey.

DISCUSSION

It may be asked whether the very satisfactory approximation:

$$\begin{aligned} 750 \text{ metres } V &= 2,425 \\ 50 \text{ metres } V &= 4,000 \\ 450 \text{ metres } V &= 2,890 \\ K &= 1,09 \end{aligned}$$

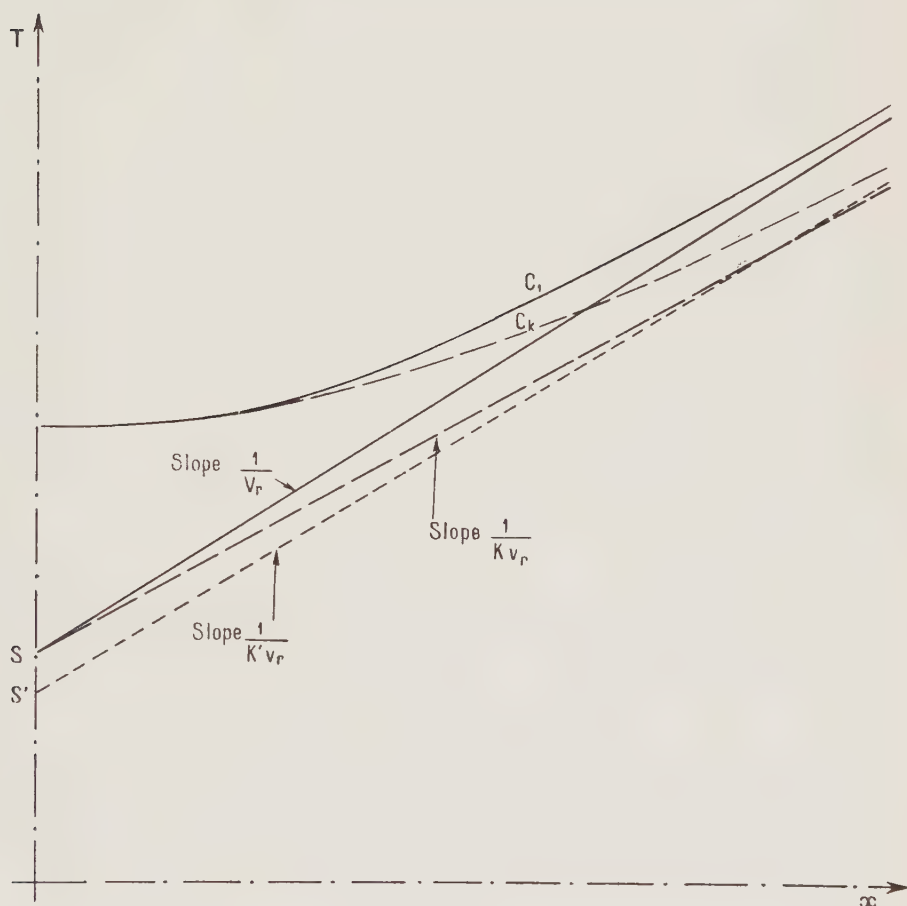


Fig. 5.

cannot be replaced by equivalent approximations within the accuracy of recordings, calculations and diagrams.

As a matter of fact, in the isotropic case $C_1: T = F(x)$ curve has an asymptote with a slope of $1/V_r$, V_r being the higher velocity of the layers (fig. 5).

For a given velocity distribution, point S where the asymptote intersects the T axis is independent of the anisotropy factor: since this factor is the equivalent of a dilatation, curve C will flatten into C_k under the effect of K whereas the asymptote will rotate around point S till its slope gets down to $\frac{1}{K V r}$

Let us suppose that the high velocity beds be thicker; Point S goes down to S' and for an adequate value K' smaller than K , the new curve will have an asymptote going through S' with a slope $\frac{1}{K' V r}$ such that the new curve C'_k will be mistaken for C_k for the x 's considered in spite of the accuracy of the measurements.

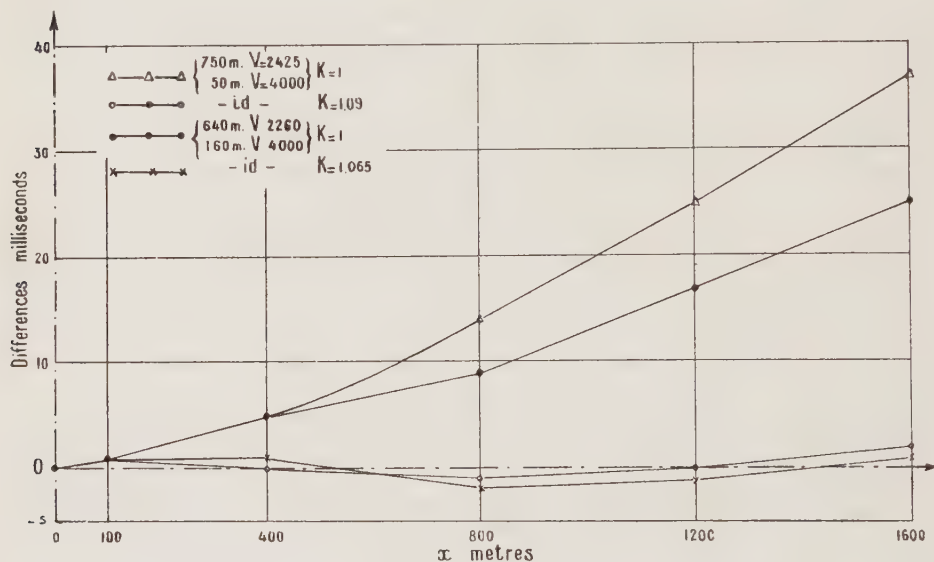


Fig. 6. Equivalent approximations.

Though the detailed lithological section makes it very unlikely to make a mistake on the evaluation of the thickness of high velocity beds, suppose, against all probability, that these layers totalize a much bigger thickness: 160 metres for instance, and let us consider the following distributions:

from 0 to 800 metres:

$$\begin{aligned} 640 \text{ m } V &= 2,260 \\ 160 \text{ m } V &= 4,000 \\ K &= 1, \text{ then } K = 1,065 \end{aligned}$$

from 0 to 1,250 metres:

$$\begin{aligned} 640 \text{ m } V &= 2,260 \\ 160 \text{ m } V &= 4,000 \end{aligned}$$

$$450 \text{ m } V = 2,890$$

$$K = 1, K = 1.07$$

Differences recorded with regard to measured values are as follows:
from 0 to 800 metres (fig. 6)

x	Differences $K=1$	Differences $K=1.065$
0	0	0
100	+1	+1
400	+5	+1
800	+9	-2
1200	+17	-1
1600	+25	+1

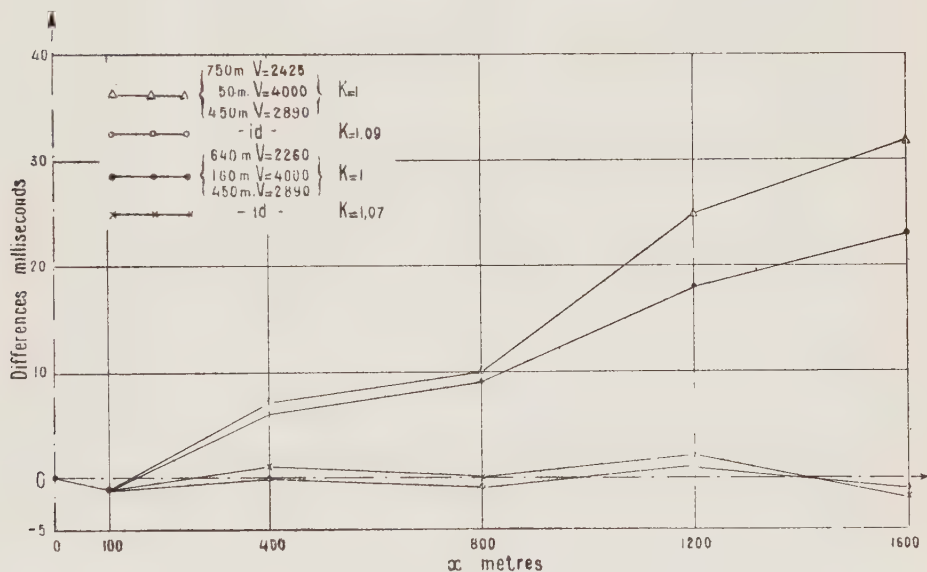


Fig. 7. Equivalent approximations.

and from 0 to 1,250 metres (fig. 7)

x	Differences $K=1$	Differences $K=1.07$
0	0	0
100	-1	-1
400	+6	+1
800	+9	0
1200	+18	+2
1600	+23	-2

Finally it is confirmed that on the assumption of high velocity layers con-

siderably thicker, the value of K obtained is noticeably lower: $K = 1.065$ between 0 and 800 metres; $K = 1.07$ between 0 and 1,250 metres.

Other similar solutions could be obtained modifying slightly V_r or using arbitrarily a velocity law increasing quickly with depth.

CONCLUSION

Calculations made lead to the following conclusions:

When high velocity layers are not taken into consideration, factor $K = 1.14$ gives a very rough approximation and the adopted value is in excess.

If the thickness of the high velocity layers is overestimated, the values $K = 1.065$ or $K = 1.07$ lead to satisfactory results, however K is too small.

Taking into account all the lithological data, K is probably close to 1.09.

A thorough discussion would require different anisotropy factors for each bed. We will grant however that obtaining coherent results from 0 to 800 metres and from 0 to 1,250 metres with $K = 1.09$ makes more complex assumptions unnecessary.

This order of size being admitted, it would be interesting to make a comparison with other determinations made by other operators on clay or clay and sand formations. The results would be more accurate if the effect of high velocity layers were not combined with the effect of anisotropy.

Were the coefficients better known by seismologists it would be possible to take into account influence of anisotropy on interpretation when seismic wave paths are oblique with respect to the strata, especially in the following cases

- refraction surveys

- reflection surveys on steep dips

- indirect velocity measurements using travel times between surface and reflecting horizons.

Measurements should be made on the most common formations: sand, clay, marl, limestone

E.A.E.G. ABSTRACT SERVICE

EXPLORATION — GENERAL

112. *Geophysical Progress.*

H. C. Cortes, *Geophysics*, Vol. 18, No. 3, pp. 510-524, June, 1953.

Marked progress has been made in the amount of geophysical activity, in the number of new oilfields discovered per year based wholly or partially on geophysics, in geophysical techniques, and in education. Improvements in instrumentation, field operational procedures, and interpretation methods have steadily increased the usefulness of the three major methods — seismic, gravity, and magnetic. The development of the aerial magnetometer, especially, and the underwater gravimeter, represent notable achievements. These developments have made possible the extension of geophysical activity offshore, and in many other areas previously considered inaccessible.

Research, fundamental and applied, has expanded rapidly in recent years. New, and more direct, oil finding methods may be discovered, but more probably, existing techniques will be refined. Coordination and advancement of geology and geophysics should insure adequate production and reserves in the U.S.A. for a long time yet.

113. *Petroleum Developments in South America and Caribbean Area in 1952.*

J. F. Mason, *Bull. Amer. Ass. Petr. Geol.*, Vol. 37, No. 7, pp. 1586-1619, July, 1953.

Geophysical progress is described in this and following papers. Other areas covered are: Europe, Africa, Middle East and Far East.

114. *How Sohio trains its exploration personnel.*

M. W. Sherwin, *Oil & Gas J.*, Vol. 51, No. 52, pp. 109-110, May 4, 1953.

The exploration personnel of Sohio Petroleum Co. undergo an initial training through a 12 month course which is divided into four main phases, as follows:

Seismograph Field Party — all operations (4 months).

Gravity Field Party — all phases of operations (2 months).

Structural Geology — subsurface mapping, field studies, surface geology and allied work (3 months).

Operational Geology — well-siting, well-sample examinations, coring, logging, etc. (3 months).

For geophysical trainees, the operational geology phase is replaced by a 3-month course in geophysical instrumentation, and geophysical laboratory work.

SEISMIC — GENERAL

115. *Core Hole Velocity Surveys.*

J. B. H. Henderson & R. Brewer, *Geophysics*, Vol. 18, No. 2, pp. 324-357, April, 1953.
See A.I.O.C. *Geophys. Abstr.* 209.

116. *The Velocity and Ray Paths of Sound Waves in Deep Sea water.*

K. Dyk & O. W. Swainson, *Geophysics*, Vol. 18, No. 1, pp. 75-103, Jan., 1953.

Basic experiments conducted by the U.S. Coast and Geodetic Survey in 1933 and 1934 to determine the ray paths of sound in sea water are reported. Time-distance, frequency, and amplitude measurements were obtained both in deep sea and shallow waters off the California coast.

SEISMIC — INSTRUMENTAL

117. *Use of Magnetic Tape Recorders for Registration of Seismic Waves over short distances.* (In German).
H. Dörmann, *Ann. Geophys.*, Vol. 8, No. 3, pp. 286-293, 1952.
The cost of recording near earthquakes is lowered by using seismographs with higher limiting frequencies than normal, and the intermediate use of magnetic-tape recorders. An instrument of this type is described, and first results are discussed. Application of the magnetic-tape recorder is recommended in geophysics wherever only short pieces of the records are used; that is, wherever rare events shall be recorded with high time resolution.
118. *Patents.* Abstracts in Geophysics, Vol. 18, No. 2, p. 461, April, 1953.
U.S. 2,614,166. 14 Oct., 1952. A directive seismometer.
U.S. 2,620,890. 9 Dec., 1952. Seismic recording system with play-back magnetic recorder.
U.S. 2,622,691. 23 Dec., 1952. Marine seismic method using an auxiliary channel with a high-pass filter.
U.S. 2,623,113. 23 Dec., 1952. Seismograph mixing system.
U.S. 2,623,922. 30 Dec., 1952. Seismic shot-firing device which produces a short current pulse.
U.S. 2,623,938. 30 Dec., 1952. Moving coil seismometer.
U.S. 2,623,947. 30 Dec., 1952. A phase correction filter circuit for seismic amplifiers.

SEISMIC — FIELD TECHNIQUE

119. *Patents.* Abstracts in Geophysics, Vol. 18, no. 2, p. 461, April, 1953.
U.S. 2,614,165. 14 Oct., 1952. Marine seismometer spread which allows the instruments to sink a little when at rest, but rise to surface for towing.
U.S. 2,615,521. 28 Oct., 1952. Seismic system with charges above the earth's surface to give a shock with a flat wave front.
U.S. 2,615,522. 28 Oct., 1952. Seismic system with elevated charges giving a controlled shock wave.
U.S. 2,615,523. 28 Oct., 1952. Seismic system with elevated charges fired in succession at controlled intervals.
U.S. 2,615,524. 28 Oct., 1952. Seismic system with elevated charges giving a controlled shock wave.
U.S. 2,618,999. 25 Nov., 1952. A jetting device for placing seismic shots in silt.
U.S. 2,619,186. 25 Nov., 1952. Method of eliminating secondary impulses from gas-bubble oscillation in under-water shooting.
120. *Aerial Shooting for Seismic Exploration.*
J. J. Jakosky, Paper read at the Pacific Coast Meeting of the S.E.G. at Los Angeles, California, Oct. 31, 1952.
This paper describes developments in a new technique for air shooting. A brief account is given of early work in the use of explosives placed at a height above the earth comparable to the depth of the reflecting bed below the surface, and of the more recent work with the explosives placed close to the surface of the earth to utilize the super-sonic wave energy. A mortar is used to eject an explosive bomb. This bomb is exploded at a specific height which is a function primarily of the spread length and near-surface ground velocity, in order to minimize the detrimental effects of ground-roll and reverberation which have created such serious obstacles in previous air shooting techniques. The apparatus and bombs, and general theoretical factors are

described. Records are shown comparing the recordings from in-hole shooting with air-shots at the same shot-point, at various difficult drilling areas in the U.S.A.

SEISMIC — THEORY & RESEARCH

121. *Velocity Functions in Seismic Prospecting.*

H. Kaufman, *Geophysics*, Vol. 18, No. 2, pp. 289-297, April, 1953.

An account of the mathematical properties of velocity functions used in the seismic method of geophysical prospecting is presented. Basic equations are given for deriving various quantities of interest associated with a particular velocity function, such as average velocity as a function of depth, average velocity as a function of vertical travel time, parametric equations for displacement, depth, travel time, etc. In part I the relations are based on a given instantaneous velocity-depth function. Part II contains a similar analysis based on a given instantaneous velocity-vertical time function. The results are incorporated in tables I and II.

122. *Strain-Wave Shapes in Rock near Explosions.*

W. I. Duvall, *Geophysics*, Vol. 18, No. 2, pp. 310-323, April, 1953.

The shapes of displacement, velocity, acceleration and strain-wave pulses in solid elastic media near a spherical cavity in which the applied pressure pulse is of the general form

$$p = p_0 (e^{-\alpha t} - e^{-\beta t})$$

have been calculated. The computed strain-wave pulse shapes at various distances from the cavity are compared with typical experimentally-recorded strain-wave pulses and are shown to have similar characteristics. The shapes of the wave pulses, that is, the rise time, pulse width, etc., are shown to be functions of the applied pressure pulse, the distance from the cavity and the properties of the solid medium.

123. *Note on Wave-Guide Propagation over a shallow Salt Dome.*

L. G. Howell and C. H. Kean, *Geophysics*, Vol. 18, No. 2, pp. 338-339, April, 1953.

This note shows evidence of a duct or wave-guide type of wave propagation over a shallow salt dome located in the gulf coast.

124. *The Theory of Noise in Continuous Media.*

C. Eckart, *J. Acoust. Soc. Amer.*, Vol. 25, pp. 195-199, March, 1953.

The mathematical solution of problems involving the propagation of noise is discussed. The relation between noise and turbulence is also briefly discussed.

125. *On the Propagation of Rayleigh Waves on the Surface of a Visco-Elastic Solid.*

C. W. Horton, *Geophysics*, Vol. 18, No. 1, pp. 70-74, January, 1953.

The propagation of Rayleigh waves over the surface of a visco-elastic solid is examined. It is shown that for a Poisson solid ($\lambda = \mu$), the behaviour of the waves can be characterized by a dimensionless parameter $\delta = \omega\eta/\mu$ which is less than 0.1 for the frequencies and elastic parameters of interest in geophysics. In this expression ω = angular frequency, μ = shear modulus, η = viscosity. For small values of δ it is possible to modify the usual analysis of Rayleigh waves and obtain the new characteristics without much difficulty. It is shown that the motion of a particle on the earth's surface is changed from an ellipse to a Lissajous' figure and that the phase angle between the vertical and horizontal displacements is changed from $\pi/2$ to $(\pi/2) - 0.1488 \delta$ radians. The surface wave has an attenuation factor of $2.908 \delta/\lambda_0$ where λ_0 is the wavelength of the Rayleigh wave in the absence of internal friction.

126. *Transient Compression Waves from Spherical and Cylindrical Cavities.*

H. L. Selberg, Ark. Fysik, Vol. 5, pp. 97-108, 1952.

A preliminary attempt to describe the phenomena near a borehole after the detonation of a charge. In the first part, the author calculates the stress in an infinite elastic solid when a uniform normal pressure acts over the surface of a spherical cavity for a short time. The effect of reflected waves is not considered. The solution is illustrated by numerical results for a solid with Poisson ratio $1/4$. In the second part, the infinite solid is assumed to have a cylindrical cavity (of infinite length); in this case, the solution is derived using the Laplace transform and the properties of Bessel functions.

127. *Sound Ranging in a Medium having an unknown Constant Phase Velocity.*

W. Schriever, Geophysics, Vol. 17, No. 4, pp. 915-923, October, 1952.

A method for the sound ranging of explosions is described, in which the direction-angle of the explosion is given in terms of the ratio of the differences in the arrival times at two pairs of microphones, geophones, or hydrophones. It is unnecessary to know either the phase-velocity in the intervening medium or the absolute values of the time differences. However, the paths and the phase velocities must be such that the time differences are the same as they would be for a wave-front travelling from explosion to the microphones at some constant velocity. A rapid graphical method for determining the location of the explosion is described. The precision of the determinations is discussed.

128. *On the Period and Amplitude of Microseismic Movement.*

F. Kishinouye, Bull. Earthq. Res. Inst., Tokyo 29, Vol. 3, pp. 483-486, September, 1951.

A new instrument was designed to study microseisms at Tokyo. Two types of microseisms are described; the first of 4-sec. period and amplitudes up to 10μ , and the second of 6-sec. period and larger amplitudes.

129. *A Velocity Function including Lithologic Variation.*

L. Y. Faust, Geophysics, Vol. 18, No. 2, pp. 271-288, April, 1953.

An investigation of longitudinal seismic velocity in sedimentary rocks as a function of depth, geologic time, and lithology. A tentative lithologic parameter is designed utilising data available from conventional resistivity logs. The variables are analyzed in nearly one million feet of section represented by 150 velocity surveys. The goal of the investigation is the prediction of velocity from well logs with accuracy equal to direct measurement. While this accuracy has not been obtained, the results are encouraging. The latter portion of the paper examines the nature of the errors of prediction of the derived velocity function and suggests that the desired end may be attainable.

130. *Developments in Continuous Velocity Logging.*

R. A. Broding, G. C. Summers, and J. O. Ely, a paper read at the Annual Meeting of the S.E.G. at Houston, Texas, March 23, 1953.

Comparison of velocity data derived from continuous velocity logs with those obtained by conventional geophone surveys indicates that with the present improved velocity-logging instruments, an accuracy of 1% can be achieved in determination of total travel times from these logs. A simplified field procedure eliminates the need for a seismic crew on such surveys if the travel time to some point a short distance below surface casing can be obtained by the gun-perforator technique.

Comparison of velocity with electric and radioactivity logs indicates that in general there is a lack of evidence to support the correlating of the elastic properties with electrical or natural radioactivity properties of rock. Examples of unrelated velocity

and electrical resistivity contrasts illustrate the hazards of deriving velocity data from resistivity logs. The lack of correlation between velocity logs, core analyses, and neutron logs suggests the hazards of correlating porosity or fluid content with velocity. The good correlation that is often observed between an acoustic transmission amplitude log and the neutron log suggests that fluid content may be controlling the transmission amplitude log.

131. *The Characteristic Data of Electromagnetic Seismographs.* (In French).
G. Grenet, *Ann. Geophys.*, Vol. 8, No. 3, pp. 328-332, 1952.

It is shown that with the use of only two families of curves it is possible to determine all characteristic data for seismic instruments which combine a pendulum with one galvanometer. Some of the results are generalized for the study of arrangements which utilize several galvanometers, including those used for registration.

GRAVITY — THEORY & RESEARCH

132. *Gravity Effect of Earth Tides.*

B. Baars, *Geophysical Prospecting*, Vol. 1, No. 2, pp. 82-110, June, 1953.

The gravity effect of the earth tides was measured simultaneously at 26 stations, with two instruments at three of the stations. After a description of the stations, the corrections on the measurements are described. The results for the separate measurements are given and it can be stated that, within the accuracy of the measurements ($1 + h - \frac{3}{2}k$) is very probably constant and has a value of 1.22. If this value is combined with Nishimura's value of 0.66 for $(1 - h + k)$, it can be shown that Takeuchi's earth models fit these values provided a value of 2.7 is taken for the surface density of the earth. The importance of a constant value for $(1 + h - \frac{3}{2}k)$ in gravity surveys is pointed out.

133. *Approximation to the Lateral Variation of Residual Gravity due to a Frustrum of a Vertical Cone.*

W. R. Griffin, *Geophysics*, Vol. 18, No. 2, pp. 401-415, April, 1953.

An equation is presented in non-dimensional form. The approximation consists of considering a frustrum of a vertical cone in which the radii are small relative to the depth to its top.

The dependent variable has been taken as being the ratio of the residual gravity to the maximum residual gravity.

The independent variable was chosen as the ratio of the lateral distance (from the centre line of the frustrum to a given station) to the depth to the top of the frustrum.

The two parameters were chosen as being (a) the ratio of depth to the bottom of the frustrum to that to its top, (b) the ratio of the bottom radius to that of the top radius.

It is then shown that, for special values of the parameters, the equation gives the lateral variation of residual gravity due to cylinders, upright cones, and inverted cones as special cases.

The equation is applied to two deep salt domes whose dimensions are well known and the correlation is shown to be remarkably close.

MAGNETIC — INSTRUMENTAL

134. *Magnetic Measurements in Deep-sea Investigations: Construction of Non-Magnetic Containers.*

N. Arley, B. Lunn, M. Nielson & C. Norgaard, *Nature*, Vol. 171, No. 4348, pp. 383-384, February 28, 1953.

A description of two non-magnetic containers made to house recording magnetometers for making measurements down to depths of 10,000 m. One container is spherical with internal diameter 50 cm; the other consists of two similar spheres joined by a tube 100 cm. long. They are constructed of a new alloy which is an iron-free β -manganese bronze with high aluminium content.

135. *Magnetic Measurements in Deep-sea Investigations:*

Magnetic Investigations on the Galathea Expedition.

N. Arley, P. Andreasen, J. Espersen & J. Olsen, *Nature*, Vol. 171, No. 4348, pp. 384-385, February 28, 1953.

A description of three self-recording magnetometers for measuring 'H' and 'Z', two of the La Cour type and one self-inductor. Working methods of using these, housed in non-magnetic containers, were developed during the expedition. It was found possible to determine in about 1 hour the value of 'H' to within 5 γ at depths down to 4,000 m. Important perturbation effects of the ocean floor, when rugged, were found. 'H' and 'Z' were found to increase numerically with increasing depth below the sea level.

136. *Patents. Abstracts in Geophysics*, Vol. 18, No. 2, p. 460, April, 1953.

U.S. 2,615,957. 28 Oct., 1952. Temperature compensation magnetometer indicator.

U.S. 2,615,961. 28 Oct., 1952. A non-oriented total-field magnetometer.

U.S. 2,616,074. 28 Oct., 1952. A Hall-effect magnetometer.

U.S. 2,620,381. 2 Dec., 1952. Magnetic gradiometer, flux valve type.

137. *Electro-Magnetometer for Exploration.*

W. Rintoul, *Petroleum Engineer*, Vol. 25, No. 3, pp. B 95-96, March, 1953.

An airborne electro-magnetometer has been designed for use on a helicopter. It weighs only 207 lbs. The instrument measures to 1/50,000 part. In actual surveys, up to 1,000 sq. miles per month have been surveyed, computed, and completely analysed. The helicopter flies at an altitude of 50 to 75 feet, and at speeds less than 40 miles per hour.

OTHER METHODS

138. *Geophysical Investigations of the Ground with the "Geoskop", "Geostratimeter", and some additional Measuring Procedures.* (In German).

R. Börner, Braunkohle, Wärme und Energie, Band 3, Heft 15-16, pp. 276-82, 1951.

The "Geoskop" consists of a transmitter and a receiver. From the transmitter radio waves are partly propagated through the ground. Reception is influenced by sub-surface structures, making it possible to correlate the instrument indications with structural details of the underground.

The "Geostratimeter", a further development, is less sensitive to conditions in the upper soil layers.

139. *Geostratimeter Measurements in the Rhine Lignite and the Significance of the Impulses of the Geostratimeter for Potential New Fields.* (In German).

K. Grütjen, Braunkohle, Wärme und Energie, Band 3, Heft 15-16, pp. 283-285, 1951.

A report on surveys in the Rhine Valley, exploring for lignite, using the Geoskop and Geostratimeter methods. Interpretation of the results is impossible without geological knowledge of the area.

140. *Exploration with the Geoskop and Stratimeter in the Lignite Basin of the Rhine.* (In German).

H. Heyll, Braunkohle, Wärme und Energie, Heft 15-16, pp. 286-288, 1951.

Results of a survey, by the Geoskop and Stratimeter methods, were checked in drill holes. Graphs from the survey are compared with geologic profiles. The former have many peaks, some of which do not agree with the structure.

141. *Oil Exploration with Airborne Scintillation Counters.*
H. Lundberg, K. L. Roulston, R. W. Pringle & G. M. Brownell, *Oil in Canada*, Vol. 4, No. 33, pp. 40-42, 44-46, 1952.
Surveys with airborne scintillation counters show that radioactive lows occur over oilfields but they are surrounded by a halo of radioactivity highs. The concentration of radioactive substances over oilfields may be caused by the upward movement of ground water. A radioactive low coinciding with other geophysical anomalies enhances the possibility of an oil pool.
142. *Radioactivity Surveys Aid Prospecting for Oil and Gas.*
H. Lundberg, *Precambrian*, Vol. 25, No. 4, pp. 9, 21, 1952.
A brief summary of the use of the airborne scintillation counter in prospecting for oil, and a theory relating radioactive anomalies to the occurrence of oil and gas.
143. *Patents. Abstracts in Geophysics*, Vol. 17, No. 3, p. 627, July, 1952.
U.S. 2,581,412. 8th January, 1952. Radioactivity Prospecting Method, determining the Spectrum of Natural Neutrons emitted from the Earth.
144. *An Analysis of Airborne Surveying for Surface Radioactivity.*
J. C. Cook, *Geophysics*, Vol. 17, No. 4, pp. 687-706, October, 1952.
Quantitative estimates of the gamma radiation field intensities expected to be encountered in flights over various geologic bodies are presented. Scattering effects are included in the calculations, but several simplifying assumptions were necessary, such as assigning equal energies to all photons. Results are compared with geiger counter measurements of three kinds: near a small natural carnotite deposit, near a tenth-curie of radium, and soundings made over normal terrain at various times. It appears that anomalies from most outcrops of radioactive ores will exceed the normal fluctuation of background radiation due to topography, variations of composition of the surface, etc., only at flying altitudes of less than about 35 feet. However, such anomalies can probably be detected under favourable conditions by their characteristically pointed shape, allowing flight at higher elevations. Requirements on flight plan and instrumentation are discussed.
145. *Radioactivity in Geophysical Oil Search.*
M. V. Scherb, *Oil Forum*, Vol. 7, No. 3, pp. 89-92, March, 1953.
A discussion on radioactivity. The methods and instruments employed to measure natural radioactivity in prospecting for oil are described.
146. *Effects of the Electrical Constants of the Ground on Radio Wave Propagation.*
J. R. Wait, *Geophysics*, Vol. 18, No. 2, pp. 416-422, April 1953.

A theoretical investigation of the influence of the conditions of the ground on the propagation of radio waves. It is indicated that discontinuities of the conductivity and dielectric constant of the ground at depths down to 60 feet can modify the characteristics of the propagation at frequencies of 100 Kcs. Curves show the magnitude of the "wave tilt" of radio waves for a horizontally stratified earth. Limitations of radio wave prospecting are outlined.

147. *A Method of Increasing the Effective Resolution of Scintillation Counters.*
K. G. Standing & R. W. Peelle, Rev. Sci. Instr., Vol. 24, No. 3, pp. 193-195, March, 1953.

A system consisting of two photomultipliers viewing one scintillating crystal is given for resolving peaks in a scintillation spectrum which otherwise would overlap because of photomultiplier statistics. A differential discriminator accepts pulses from a fixed portion of the spectrum from one of the tubes. Another differential discriminator scans the spectrum from the second tube and is coincidence-gated by the first. Experimental results are presented which show that this method can separate monoenergetic lines not otherwise resolved.

THE PREPARATION OF PAPERS FOR "GEOPHYSICAL PROSPECTING" AND THEIR PRESENTATION AT TECHNICAL MEETINGS

BY

J. M. BRUCKSHAW *

ABSTRACT

The efficient production of "Geophysical Prospecting" depends upon the co-operation of the individual authors and this paper serves as a guide for them. Some suggestions are also made on the presentation of papers at meetings in the hope of promoting successful discussions.

Even with the limited experience gained in the preparation of the first volume of "Geophysical Prospecting" it has become evident that considerable delays in publication have occurred because the manuscript and the diagrams have not been submitted in a suitable form. This is more especially true of the diagrams since the effect of the reduction in size to fit a page of the Journal is not fully appreciated. Apart from the delay, the subsequent correspondence with the authors is extra work which could be avoided so that the burden, voluntarily carried by the Editor and other Officers of the Association, could be lightened. This paper is written as a guide to prospective authors and it is hoped that, by adhering to the general rules and simple instructions outlined, a more efficient service will become available to Members.

SUBJECT MATTER OF PAPERS

Papers must be communicated by Members and may be their own contribution or a paper written by a non-member. In the latter case the communicating Member should satisfy himself that the contribution is of sufficient merit. The type of paper acceptable for publication is one which is consistent with the aims and objects of the Association. Thus, advances in theory, in instrument design or in field procedure of any present day method or new method, improvements in computation or interpretation, the results of field work involving some unusual or novel feature, the use of several methods in the same area and their integration into a final consistent picture, contributions to safety, etc., would all be suitable topics for a paper. Naturally, the main interest is in the search for mineral resources but papers on more academic topics and the

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physical properties of materials are also desirable if they have some bearing on problems of prospecting or may lead to new developments.

Of necessity, most geophysical work is of a confidential nature and it is the author's responsibility to obtain permission for publication from the appropriate concerns. Again, when new developments or new methods are discussed they must be described in reasonable detail. If this condition cannot be met, then the paper would not be acceptable.

FORM OF MANUSCRIPTS

Manuscripts must be submitted in duplicate. These should be typed on one side of the paper only, using double spacing with a wide margin (at least 2.5 cm) on the left. Any corrections made by the author should not be made in this margin which is required by the Editor to give necessary instructions to the printer. The paper should be accompanied by two sets of diagrams, one set preferably on tracing paper or cloth and the other set printed from the original. To assess the papers they will be examined critically by the Editors and, in most cases, by referees who will be experts in the subject of the paper. This examination will obviously be expedited with two copies and, since the prints will be sent through the post, the original diagrams will not be damaged.

The general style and arrangement of the paper is left in the hands of the author, but the question of cost of printing and, in particular, of reproducing diagrams should always be borne in mind. The paper can be written in either English, French or German, but in all cases it must be preceded by a short abstract, of a few hundred words, in English. To a reader with a reasonable knowledge of the subject the abstract should give a brief but comprehensive picture of the contents (Landes, 1951), drawing attention to any new information and the conclusions reached. It is also of assistance to the reader if the paper is divided into sections with appropriate headings. In addition to acting as a guide to the contribution, such headings assist in the location of any particular point at a later date.

REFERENCES

In the text, references to work previously published should be indicated by the name of the author and the year of publication placed between brackets. If the sentence contains the name of the author then the year of publication, again in brackets would be adequate. Thus, either of the forms "It has been shown (Richard 1953) that ..." or "Richard (1953) has shown that ..." may be used. At the end of the paper a detailed list of the references is necessary. In this list the authors are arranged in alphabetical order and, if several papers by the same author are involved, these are arranged chronologically. Where reference is made to a number of papers by the same author with a common

year of publication, they should be distinguished by the addition of a, b, c, etc. after the year, both in the text and in the list. The citation of the paper should follow the standard pattern of Surname, Initial, Year, Title of paper, the Journal, the Volume and the Page numbers. Corresponding to the example suggested above, there would appear in the list the entry

Richard H., 1953, *Réflexions multiples obliques*, Geophysical Prospecting, 1, 49-63.

For a book the pattern would be Surname, Initial, Year of publication, Title of book, the Edition, Page of reference and the Printer, thus

Eve A. S. and Keys D. A., 1938, *Applied Geophysics*, 3rd Ed., 177, University Press Cambridge.

For most journals there are recognised abbreviated titles and, to maintain a consistent system, it is recommended that the abbreviations, listed in Geophysical Abstracts 152, Geological Survey Bulletin 1002-A, U.S. Department of the Interior, should be used.

FORMULAE

In mathematical expressions, printing is facilitated by using the solidus (/) for division and relatively complicated expressions can be printed in a single line by using this symbol in conjunction with brackets. As an example the space for the two identical expressions

$$\frac{x \left(1 - \frac{x^2}{a^2} \right)^2}{\left(1 + \frac{x^2}{a^2} \right)^{5/2}} \tan \theta$$

and $\{(x/a) (1 - x^2/a^2)^2 \tan \theta\} / (1 + x^2/a^2)^{5/2}$ should be compared. When using this system care must be exercised in placing the brackets, since different meanings are attached to $(\sin x) / a$ and $\sin x / a$.

TABLES AND DIAGRAMS

The results of observations are usually given in the form of tables or diagrams. These are alternative methods of giving the same information and, as a general rule, one method only should be used. The particular system employed will be controlled by the purpose of the contribution and the nature of the conclusions to be drawn. Very occasionally, both methods may be desirable as, for example, when a series of accurate gravity observations establish a set of reference stations for general use and the discussion includes the nature of the space variation between them. The former requires a table and the latter some graphical representation. Where possible, both diagrams and tables should be designed to appear upright on a page. The captions and legends

attached to diagrams should appear in English as well as in the language of the contribution.

The size of the published diagrams is limited to the page size of "Geophysical Prospecting" i.e. about 12 cm by 18 cm. Accordingly, many original diagrams must be reduced and, unless precautions are taken, they appear weak and confused and the printing is too small to be legible. The weak appearance is due to the resulting thin lines. Normal eyes can appreciate a line whose thickness subtends an angle of 1 min. of arc i.e. 0.07 mm at the distance of distinct vision (25 cm). Making allowances for variations in eyesight, a minimum

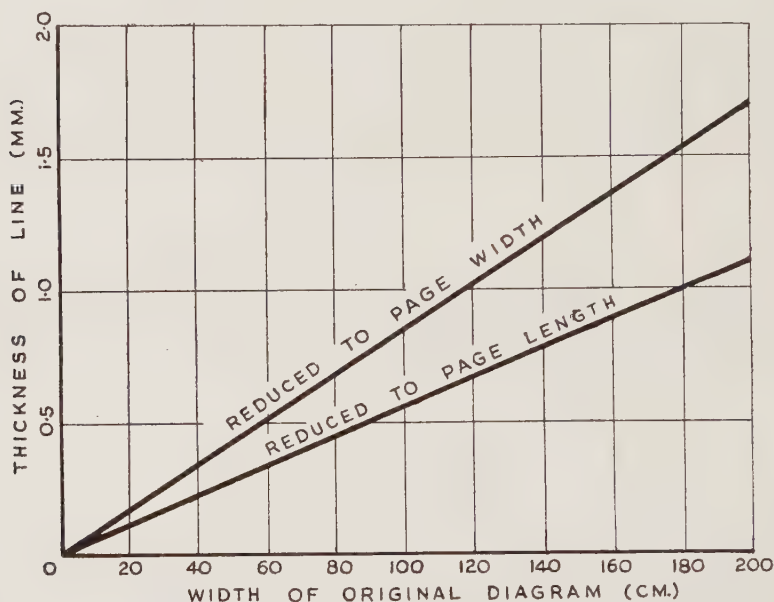


Fig. 1. Graph showing minimum thickness of lines on original diagram.

thickness of 0.1 mm in the printed diagram would be permissible. Fig. 1 shows graphically the minimum thickness of line on the original diagram, plotted against diagram size, to give a satisfactory line when reduced to a page width and to a page length. The more important parts of the diagram should, of course, be in thicker lines.

Similar considerations apply to the printing. As a guide, the lower case letters of this journal are about 1.6 mm high and the capitals 2.4 mm. In the smaller printing of the abstracts these heights are 1.4 mm and 2.1 mm respectively and it is claimed that printing about 0.4 mm is legible. Again allowing for the vagaries of the individual, 0.8 mm is a reasonable minimum. Figs. 2 and 3 again show graphically the size of lettering, plotted against original diagram

size, required to give a size as reproduced equal to this minimum and also to give lettering comparable with the normal lower case lettering.

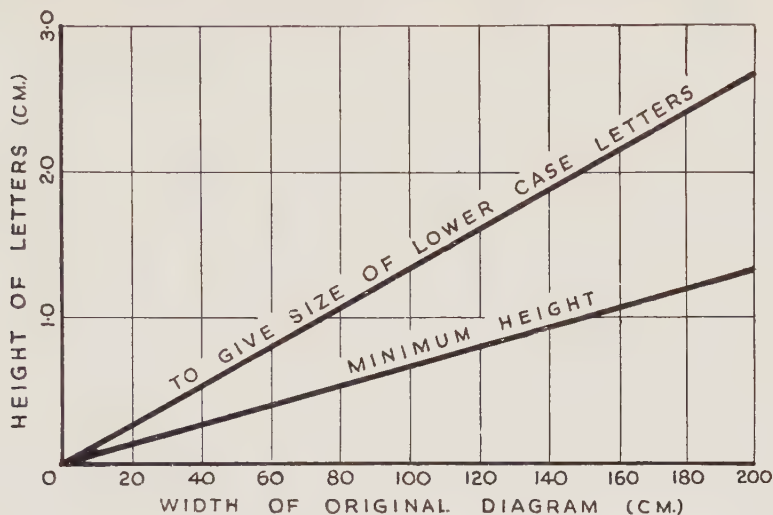


Fig. 2. Size of lettering on original diagram for reduction to page width.

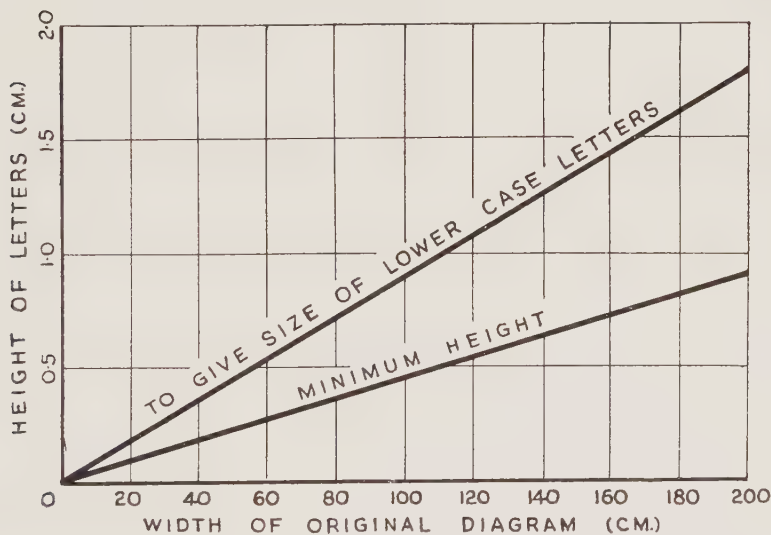


Fig. 3. Size of lettering on original diagram for reduction to page length.

Finally, the amount of detail which can be incorporated on a large diagram, without detracting from its usefulness, is far in excess of that suitable for a small diagram which, when reduced from the detailed larger version, becomes

confusing and unsatisfactory. Thus, it is obvious that maps must be especially drawn for publication in the journal. The simplest method is to trace from the original those features essential to the final diagram in lines of appropriate relative thickness, and to add lettering of adequate height.

THE PRESENTATION OF PAPERS AT MEETINGS

The presentation of papers at Technical meetings raises a number of questions, by far the most important being the difficulty of language. Many members can read with facility some language other than their own but find difficulty in following the spoken word. Since the most important benefit arising from meetings is the discussion of papers, some time devoted to the preparation of a version suitable for presentation to an audience is well worth while. In addition, the discussions will benefit greatly if a draft summary of the paper can be prepared by the author to be circulated to Members at the Meeting or, preferably, before the Meeting.

The time allocated to each paper is usually 45 minutes but of this only 25-30 should be occupied with the communication by the member, the remainder being for discussion. This time does not permit a contribution longer than 2500-3000 words, the actual number depending naturally upon the language and the individual. In addition the paper prepared for publication is not, as a general rule, in the most suitable form for delivery to an audience, and it is recommended that a shortened version should be prepared for the meeting. Care should be taken in its preparation and, because of the language difficulty, a simple direct style should be adopted. Where possible the paper should not be read but the author should talk to the meeting. Again, although most members have a general knowledge of many aspects of geophysical prospecting they will be experts in only one branch which may not be the subject of the paper, a point which should be always borne in mind. It would be impossible to formulate a scheme which would be applicable to all types of contribution but the following outline, suitable for an experimental investigation, may serve as a guide.

- 1) The general background into which the work fits leading to a definition of the problem investigated.
- 2) Sufficient details of any experiments to show the full conditions of operation.
- 3) The experimental results and a discussion of their significance.
- 4) The final conclusions from the work pointing to an advance in the subject or leading the way to a future advance.

In the case of a mathematical investigation, 2) would be the formulation of the mathematical problem from the physical conditions bringing out the assumptions involved in this process and the additional assumptions made in the solution. Details of the mathematical manipulation are not desirable.

THE PROJECTION OF DIAGRAMS

When diagrams are shown at meetings these should be in the form of slides of standard dimensions. Diagrams projected by epidiascope should be avoided because of the poor illumination obtained. The minimum size of lettering etc. on a diagram which after projection as a slide will be legible over the whole auditorium depends on a number of factors. Knapp (1928) has shown that

$$h = 0.0015 \, Ac/P$$

when h is the minimum height of the original letters, A is the maximum audience distance, c the width of the original copy and P is the width of the projection on the screen. (Note that if A and P are in the same units, h will be in the same units as c). Since the meetings are held in a variety of rooms the precise specification of the lettering is difficult. Taking, however, $P = 2$ m and $A = 18$ m, then $h = 0.0135 \, c$. It will be found that the weight of the lines (Moore, 1942) should be somewhat greater for a good slide and the lettering should be more widely spaced than in the case of a diagram. Finally, all slides should be marked in a standard manner so that the lantern operator cannot insert them wrongly. It is usual to put a white mark at the top on the front face of the slide.

ACKNOWLEDGEMENT

The author wishes to acknowledge a debt to L. L. Nettleton (1945) from whose article in "Geophysics" on a similar topic he has freely drawn.

REFERENCES

- KNAPP A., 1928, Technical Papers and their Presentation, Am. Assoc. Petroleum Geologists, Bull., 12, 77-83.
LANDES K. K., 1951, A Scrutiny of the Abstract, Am. Assoc. Petroleum Geologists, Bull., 35, 1660.
MOORE C. A., 1942, Preparation of Lantern Slide Copy, Am. Assoc. Petroleum Geologists, Bull., 26, 1656-1671.
NETTLETON L. L., 1945, Preparation of Manuscripts for Publication in Geophysics, Geophysics, 10, 421-428.

DIE ABHÄNGIGKEIT DES SCHEINBAREN WIDERSTANDES VOM SONDENABSTAND BEI DER VIERPUNKT-METHODE *

VON

K. DEPPERMAN **

ABSTRACT

The dependence of the apparent resistivity on the distance between the potential electrodes is examined and a numerical method is described permitting quantitative calculations. Such a numerical relation is also established for the transformation of Wenner graphs into Schlumberger graphs.

In addition it is shown, in which manner the jumps in observed Schlumberger curves, that result from changing the probe spacing, must be smoothed out.

Geoelektrische Tiefensonierungen werden in Schlumberger- oder Wenner-Anordnung vorgenommen. Zur Charakterisierung der elektrischen Eigenschaften des Untergrundes benutzt man dabei den scheinbaren Widerstand, dessen

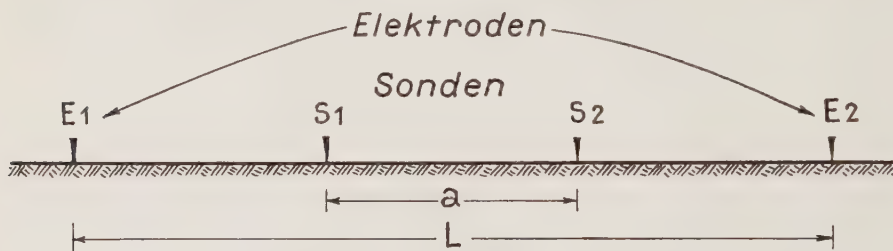


Abb. 1. Bezeichnungen. — Symbols.

Änderungen in Abhängigkeit von der Elektrodenentfernung betrachtet werden. Unter der Voraussetzung, dass das Potentiallinienbild einer Punktquelle sich nicht ändert, wenn diese in der Messgeraden verschoben wird, führen beide Anordnungen zu äquivalenten Ergebnissen. Es ist aber keinesfalls so, dass der zur gleichen Elektrodenentfernung L in Schlumberger- oder Wenner-Anordnung bestimmte scheinbare Widerstand übereinstimmt. Dies ist nur unter speziellen Bedingungen der Fall. Im allgemeinen hängt der scheinbare Widerstand noch vom Sondenabstand a ab, genauer gesagt vom Verhältnis a/L . Dieses ist bei Sondierungen in Schlumberger-Anordnung veränderlich und soll theoretisch

* Presented at the Copenhagen Meeting of the European Association of Exploration Geophysicists, 19/22 May 1954.

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der Bedingung $\lim a/L = 0$ genügen, die sich praktisch jedoch nicht genau erfüllen lässt. Zur Vermeidung von Fehlern bei der Deutung von Schlumbergermessungen ist es daher von Bedeutung, die Beeinflussung des Kurvenverlaufs durch Änderungen von a/L zu kennen.

Bei Tiefensondierungen in Wenner-Anordnung treten derartige Schwierigkeiten offenbar nicht auf, da $a/L = 1/3$ konstant gehalten wird. Es machen sich dafür aber andere Störungen im Kurvenverlauf bemerkbar, die bei Messungen in Schlumberger-Anordnung nicht in Erscheinung treten. Ihre Ursache haben diese Störungen in den normalerweise im Untergrund regellos eingestreuten lokalen Inhomogenitäten, die bedingen, dass das Potentiallinienbild beim Verschieben einer Punktquelle längs der Messgeraden nicht invariant bleibt. Es wird gezeigt, dass die Tiefeneffekte bei der Schlumberger-Anordnung deutlicher in Erscheinung treten, als bei der Wenner-Anordnung. Die durch Änderungen von a/L bedingten Einflüsse auf den Verlauf einer Schlumberger-Kurve machen diesen Vorteil nicht wieder zunichte, da sie gesetzmässig erfolgen und berücksichtigt werden können. Die Schlumberger-Anordnung ist also vorteilhafter.

Das Ziel der folgenden Untersuchung soll nun sein, die Abhängigkeit des scheinbaren Widerstandes vom Verhältnis a/L zu klären. Dies geschieht mit Hilfe eines numerischen Verfahrens, dass die quantitative Abhängigkeit von a/L liefert. Das Verfahren gestattet auch, Wennerkurven in Schlumbergerkurven umzurechnen. Dies ist von Interesse, da für die Wenner-Anordnung Auswertmaterial in grösserer Menge berechnet wurde.

1. Es sei vorausgesetzt, dass das Potentiallinienbild einer Punktquelle invariant bleibt, wenn diese in der Messgeraden verschoben wird. Der scheinbare Widerstand $\rho^{(a/L)} (L/2)$ wird dann definiert durch den Ausdruck:

$$\rho^{(a/L)} \left(\frac{L}{2} \right) = \frac{2\pi}{I} \frac{\left(\frac{L}{2} \right)^2 - \left(\frac{a}{2} \right)^2}{a} \left[V \left(\frac{L+a}{2} \right) - V \left(\frac{L-a}{2} \right) \right] \quad (1)$$

worin V das Potential bedeutet, das beim Einleiten des Stromes I in den Boden entsteht.

Für die Schlumberger-Anordnung führt man den scheinbaren Widerstand durch den Ausdruck

$$\rho^{(0)} \left(\frac{L}{2} \right) = \frac{2\pi}{I} \left(\frac{L}{2} \right)^2 \frac{dV \left(\frac{L}{2} \right)}{d \left(\frac{L}{2} \right)} \cdot \cdot \cdot \cdot \cdot \quad (2)$$

ein, der sich aus (1) durch den Grenzübergang $\lim a/L = 0$ ergibt.

Als analytischen Zusammenhang zwischen (1) und (2) findet man:

$$\rho^{(a)}\left(\frac{L}{2}\right) = \frac{\left(\frac{L}{2}\right)^2 - \left(\frac{a}{2}\right)^2}{a} \int_{\frac{L-a}{2}}^{\frac{L+a}{2}} \frac{\rho^{(o)}(x)}{x^2} dx \cdot \cdot \cdot \cdot \cdot \quad (3)$$

Aus (3) lassen sich wesentliche Schlüsse auf das Verhalten von Sondierungskurven bei unterschiedlichem a/L ziehen.

a) Ist $\rho^{(o)}\left(\frac{L}{2}\right) = \text{const.}$, so gilt: $\rho^{(a)}\left(\frac{L}{2}\right) = \rho^{(o)}\left(\frac{L}{2}\right)$ und umgekehrt.

Ist nämlich $\rho^{(o)}(L/2)$ konstant, so kann man in (3) die Integration ausführen und erhält

$$\rho^{(a)}\left(\frac{L}{2}\right) = \rho^{(o)}\left(\frac{L}{2}\right) = \text{const.}$$

Um die Umkehrung zu zeigen, wird (3) nach $L/2$ differenziert. Durch geeignete Umformung erhält man

$$\frac{(L+a)^2}{4aL} \rho^{(o)}\left(\frac{L-a}{2}\right) - \frac{(L-a)^2}{4aL} \rho^{(o)}\left(\frac{L+a}{2}\right) = \rho^{(a)}\left(\frac{L}{2}\right) - \frac{L^2 - a^2}{4L} \frac{d \rho^{(a)}\left(\frac{L}{2}\right)}{d \left(\frac{L}{2}\right)}$$

Mit $\rho^{(a/L)}(L/2) = \text{const.}$ geht die Gleichung über in den Ausdruck

$$\frac{(L+a)^2}{4aL} \rho^{(o)}\left(\frac{L-a}{2}\right) - \frac{(L-a)^2}{4aL} \rho^{(o)}\left(\frac{L+a}{2}\right) = \rho^{(a)}\left(\frac{L}{2}\right) = \text{const}$$

der für jedes L gelten muss. Daraus folgt aber

$$\rho^{(o)}\left(\frac{L-a}{2}\right) = \rho^{(o)}\left(\frac{L+a}{2}\right) = \rho^{(a)}\left(\frac{L}{2}\right) = \text{const.}$$

Insbesondere bedeutet dies, dass der scheinbare Widerstand bei jeder Messanordnung den gleichen asymptotischen Werten zustrebt.

b) Wird der Sondenabstand gleich dem Elektrodenabstand, so erhält man keine Tiefenwirkung mehr.

Zum Beweise bilden wir in (3) den Grenzwert

$$\lim_{a \rightarrow L} \rho^{(a)}\left(\frac{L}{2}\right) = \lim_{a \rightarrow L} \frac{\left(\frac{L}{2}\right)^2 - \left(\frac{a}{2}\right)^2}{a} \int_{\frac{L-a}{2}}^{\frac{L+a}{2}} \frac{\rho^{(0)}(x)}{x^2} dx = \lim_{a \rightarrow L} \frac{\int_{\frac{L-a}{2}}^{\frac{L+a}{2}} \frac{\rho^{(0)}(x)}{x^2} dx}{\frac{\left(\frac{L}{2}\right)^2 - \left(\frac{a}{2}\right)^2}{a}}$$

Der Rechts in der Gleichung stehende unbestimmte Ausdruck ist von der Form $\frac{\infty}{\infty}$. Wir bestimmen seinen Grenzwert nach der Regel von l'Hospital.

$$\lim_{a \rightarrow L} \rho^{(a)}\left(\frac{L}{2}\right) = \frac{\frac{d}{da} \left(\int_{\frac{L-a}{2}}^{\frac{L+a}{2}} \frac{\rho^{(0)}(x)}{x^2} dx \right)}{\frac{d}{da} \left(\frac{a}{\left(\frac{L}{2}\right)^2 - \left(\frac{a}{2}\right)^2} \right)} \quad (a = L) = \rho^{(0)}$$

$\rho^{(0)}(0) = \rho_1$ ist aber der spezifische Widerstand der Deckschicht.

Die Betrachtung lehrt, dass eine Zweipunktmethode sinnlos ist, da sie keine Tiefenwirkung erzeugt.

c) In einem Schlumberger-Diagramm spiegeln sich die elektrischen Eigenschaften des Untergrundes am markantesten wider.

Dies folgt aus der Tatsache, dass der scheinbare Widerstand nach (3) durch eine Mittelwertbildung über einen Teil des Schlumberger-Diagrammes entsteht.

d) Im ansteigenden Kurventeil liegt das Schlumberger-Diagramm oberhalb, im abfallenden Kurventeil dagegen unterhalb jeder Sondierungskurve mit $a/L > 0$.

Dies folgt aus der speziellen Art der Mittelwertbildung in (3).

Hiernach gehen wegen des Faktors $1/x^2$ im Integranden die Widerstandswerte am Anfang des Integrationsintervalles mit grösserem Gewicht in die Mittelwertbildung ein, als die Widerstandswerte am Ende des Integrationsintervalles (s. Abb. 2).

2. Mittels (3) lassen sich einfache numerische Formeln ableiten, die zur quantitativen Darstellung des Einflusses von a/L auf den Verlauf von Sondierungskurven benutzt werden können. Die Formeln gewinnt man nach folgender Methode: Die Schlumbergerkurve $\rho^{(0)}(L/2)$ sei gegeben. Sie wird durch ein Lagrange'sches Interpolationspolynom approximiert, welches in Gleichung (3)

eingesetzt wird. Die Integration lässt sich allgemein ausführen. Als Ergebnis erhält man eine Gleichung, in der die zur Aufstellung des Interpolationspolynoms benutzten $\rho^{(0)}$ -Werte mit gewissen Koeffizienten behaftet sind. Die Koeffizienten hängen von der Abszisseneinteilung und dem Verhältnis a/L ab. Die Gleichung kann einmal dazu benutzt werden, um aus einer Schlumbergerkurve punktweise die zugehörige $\rho^{(a/L)}$ -Kurve zu konstruieren. Ebenso kann die Gleichung aber auch umgekehrt dazu benutzt werden, um aus der $\rho^{(a/L)}$ -Kurve punktweise die Schlumbergerkurve $\rho^{(0)}(L/2)$ zu berechnen.

Die nach dieser Methode gewonnenen Formeln gelten natürlich nur näher-

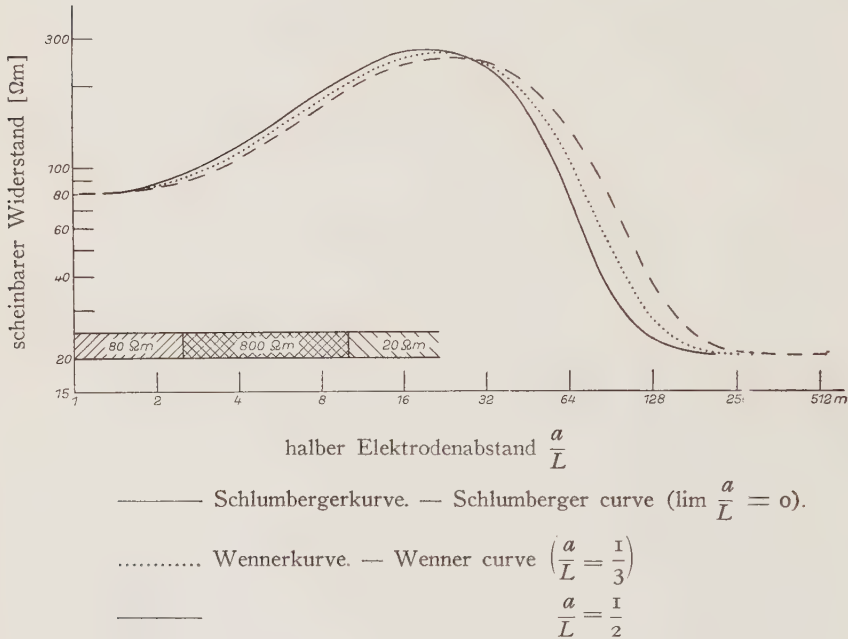


Abb. 2. Widerstandskurven bei verschiedenen Verhältnissen $\frac{a}{L}$. — Resistivity curves

with different $\frac{a}{L}$ ratios.

ungsweise. Ihre Genauigkeit hängt wesentlich von der Anzahl der Interpolationsstellen ab. Da sich Sondierungskurven aber relativ wenig ändern, kommt man mit wenigen Interpolationsstellen bereits zu hinreichenden Genauigkeiten für die Praxis.

Das Gleichungssystem (4) ist nach dem oben beschriebenen Prinzip berechnet worden.

$$\begin{aligned}
\rho^{(\frac{1}{2})}\left(\frac{L}{2}\right) &= 0,2023 \rho^{(0)}\left(\frac{L}{2} \cdot \frac{1}{2}\right) + 0,3985 \rho^{(0)}\left(\frac{L}{2} \cdot \frac{1}{\sqrt{2}}\right) + 0,2982 \rho^{(0)}\left(\frac{L}{2}\right) + \\
&\quad + 0,1010 \rho^{(0)}\left(\frac{L}{2} \cdot \sqrt{2}\right) \\
\rho^{(\frac{\sqrt{2}}{4})}\left(\frac{L}{2}\right) &= 0,0195 \rho^{(0)}\left(\frac{L}{2} \cdot \frac{1}{2}\right) + 0,3506 \rho^{(0)}\left(\frac{L}{2} \cdot \frac{1}{\sqrt{2}}\right) + 0,5649 \rho^{(0)}\left(\frac{L}{2}\right) + \\
&\quad + 0,0649 \rho^{(0)}\left(\frac{L}{2} \cdot \sqrt{2}\right) \\
\rho^{(\frac{1}{4})}\left(\frac{L}{2}\right) &= -0,0089 \rho^{(0)}\left(\frac{L}{2} \cdot \frac{1}{2}\right) + 0,2102 \rho^{(0)}\left(\frac{L}{2} \cdot \frac{1}{\sqrt{2}}\right) + 0,7629 \rho^{(0)}\left(\frac{L}{2}\right) + \\
&\quad + 0,0358 \rho^{(0)}\left(\frac{L}{2} \cdot \sqrt{2}\right) \cdot \cdot \cdot \cdot \cdot \cdot \quad (4) \\
\rho^{(\frac{\sqrt{2}}{8})}\left(\frac{L}{2}\right) &= +0,0092 \rho^{(0)}\left(\frac{L}{2} \cdot \frac{1}{2}\right) + 0,0798 \rho^{(0)}\left(\frac{L}{2} \cdot \frac{1}{\sqrt{2}}\right) + 0,8955 \rho^{(0)}\left(\frac{L}{2}\right) + \\
&\quad + 0,0155 \rho^{(0)}\left(\frac{L}{2} \cdot \sqrt{2}\right) \\
\rho^{(\frac{1}{8})}\left(\frac{L}{2}\right) &= -0,0055 \rho^{(0)}\left(\frac{L}{2} \cdot \frac{1}{2}\right) + 0,0588 \rho^{(0)}\left(\frac{L}{2} \cdot \frac{1}{\sqrt{2}}\right) + 0,9372 \rho^{(0)}\left(\frac{L}{2}\right) + \\
&\quad + 0,0095 \rho^{(0)}\left(\frac{L}{2} \cdot \sqrt{2}\right) \\
\rho^{(\frac{1}{16})}\left(\frac{L}{2}\right) &= -0,0028 \rho^{(0)}\left(\frac{L}{2} \cdot \frac{1}{2}\right) + 0,0296 \rho^{(0)}\left(\frac{L}{2} \cdot \frac{1}{\sqrt{2}}\right) + 0,9684 \rho^{(0)}\left(\frac{L}{2}\right) + \\
&\quad + 0,0048 \rho^{(0)}\left(\frac{L}{2} \cdot \sqrt{2}\right)
\end{aligned}$$

Es wurde bei der Abszisseneinteilung $\dots, \frac{1}{2}, \frac{1}{\sqrt{2}}, 1, \sqrt{2}, 2, \dots$ durch je vier aufeinander folgende Schlumbergerpunkte ein Näherungspolynom 3. Grades gelegt und das Integrationsintervall so gewählt, dass es von den vier Abszissenteilpunkten überdeckt wurde. Die weiteren dies betreffenden Einzelheiten sind aus (4) ersichtlich.

Die Gleichungen können dazu benutzt werden, um zu einer idealen Schlumbergerkurve $\rho^{(0)}(L/2)$ jene Kurvenzweige zu berechnen, die zu einem festen Sondenabstand gehören. Ein Beispiel dafür zeigt Abb. 3. Kurvenpunkte können nur an solchen Stellen $L/2$ umgerechnet werden, zu denen eine der Gleichungen passt. In (4) sind die Verhältnisse a/L jedoch so gewählt, dass man zum Zeichnen der neuen Kurve eine hinreichend dichte Punktfolge erhält.

Umgekehrt kann man nach (4) zu Kurvenzweigen, die bei festem a gemessen wurden, die Idealkurve $\rho^{(0)}(L/2)$ berechnen. Bei Feldmessungen können sich hierbei allerdings Schwierigkeiten ergeben, auf die wir noch zu sprechen kom-

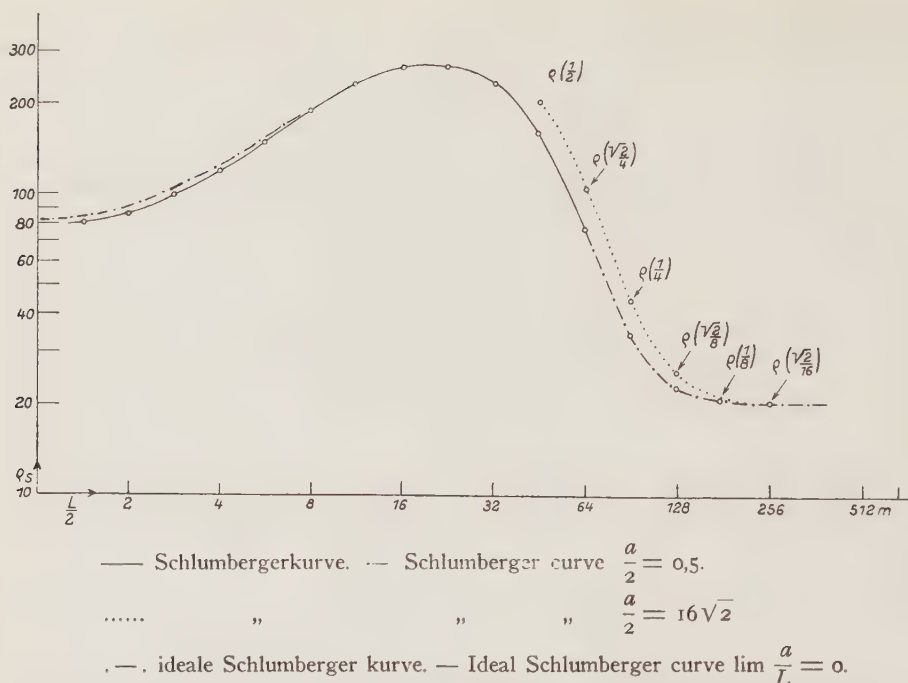


Abb. 3. Sondierungskurve bei festem Sondenabstand. — Resistivity curve with fixed probe spacing.

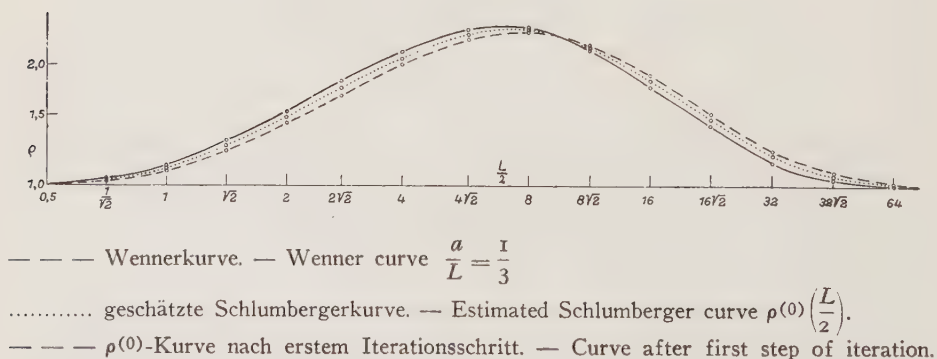


Abb. 4. Überführung einer Wennerkurve in eine Schlumbergerkurve. — Transformation of a Wenner curve into a Schlumberger curve.

men. Nach welchem Prinzip die Berechnung der Kurve $\rho^{(0)}(L/2)$ nun erfolgt, sei am Beispiel einer Wennerkurve erläutert. In diesem Falle erhalten wir anstelle von (4) die eine Gleichung

$$\rho^{(1/3)}\left(\frac{L}{2}\right) = 0,0095 \rho^{(0)}\left(\frac{L}{2} \cdot \frac{1}{2}\right) + 0,3260 \rho^{(0)}\left(\frac{L}{2} \cdot \frac{1}{\sqrt{2}}\right) + 0,6054 \rho^{(0)}\left(\frac{L}{2}\right) + \\ + 0,0590 \rho^{(0)}\left(\frac{L}{2} \cdot \sqrt{2}\right) \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \quad (5)$$

Zu dem gegebenen Verlauf der Wennerkurve lässt sich der Verlauf der Schlumbergerkurve $\rho^{(0)}(L/2)$ nach Abschnitt (1, d) etwa schätzen (s. Abb. 4). Es wird nun mit Gleichung (5), beginnend am Anfang der Wennerkurve, wo diese nach Abschnitt (1, a) mit der Schlumbergerkurve identisch ist, kontrolliert, ob der geschätzte Kurvenverlauf bereits ideal ist. Wird Gleichung (5) nicht erfüllt, so muss der mit dem grössten Koeffizienten behaftete $\rho^{(0)}$ -Wert — das ist $\rho^{(0)}(L/2)$ — entsprechend geändert werden. Die abgeänderten $\rho^{(0)}$ -Werte legen einen verbesserten Verlauf der Schlumbergerkurve fest, auf die das Iterationsverfahren erneut angewendet werden kann. Im allgemeinen kommt das Iterationsverfahren bereits nach dem zweiten Schritt zum Stehen.

Zum Bestimmen der Kurve $\rho^{(0)}(L/2)$ aus vorgegebenen, zu festem a gemessenen Kurventeilen verfährt man entsprechend. Wesentlich ist, dass man in jenen Kurventeilen mit der Umrechnung beginnt, die mit der Schlumbergerkurve identisch sind. Der Anfang eines neuen Kurvenstückes muss daher das vorhergehende überlappen (s. Abb. 3).

3. Auf Feldmessungen lassen sich die numerischen Formeln nicht ohne weiteres anwenden, weil hierbei die am Anfang des Abschnittes 1 getroffene Voraussetzung in der Regel nicht erfüllt ist. Wir diskutieren die veränderten Verhältnisse zunächst für die Schlumberger-Anordnung. Dazu machen wir von dem Vertauschungssatz Gebrauch, wonach man zu gleichen Messergebnissen kommt, wenn man den Strom an den Sonden einleitet und die Spannung an den Elektroden misst. Nach dieser Vorstellung bedeutet eine Sondierung in Schlumberger-Anordnung das Abtasten des Potentialfeldes zweier fest an der Erdoberfläche verharrenden Punktquellen. Ist V_1 das von der Punktquelle S_1 und V_2 das von der Punktquelle S_2 erzeugte Potential, so ergibt sich anstelle von (1)

$$\rho^{(a)}\left(\frac{L}{2}\right) = \frac{2\pi}{I} \frac{\left(\frac{L}{2}\right)^2 - \left(\frac{a}{2}\right)^2}{a} \cdot \\ \cdot \frac{V_1\left(\frac{L+a}{2}\right) - V_2\left(\frac{L-a}{2}\right) + V_2\left(-\frac{L+a}{2}\right) - V_1\left(-\frac{L-a}{2}\right)}{2} \quad (6)$$

Ist nun $a \ll L$, dann kann man näherungsweise setzen:

$$V_2\left(\frac{L-a}{2}\right) \sim V_1\left(\frac{L-a}{2}\right); V_2\left(-\frac{L+a}{2}\right) \sim V_1\left(-\frac{L+a}{2}\right)$$

und (6) geht über in

$$\rho \left(\frac{a}{L} \right) \left(\frac{L}{2} \right) = \frac{2\pi}{I} \frac{\left(\frac{L}{2} \right)^2 - \left(\frac{a}{2} \right)^2}{a}.$$

$$\frac{V_1 \left(\frac{L+a}{2} \right) - V_1 \left(\frac{L-a}{2} \right) + V_1 \left(-\frac{L+a}{2} \right) - V_1 \left(-\frac{L-a}{2} \right)}{2} \quad (7)$$

Aus (7) geht hervor, dass bei Messungen in Schlumbergeranordnung nur solche oberflächlichen Störungen die Tiefeneffekte überlagern, die das Potential V_1 in der Nähe der Elektroden verzerren.

Anders ist dies bei Messungen in Wenneranordnung. Beim Verändern des Elektrodenabstandes wird auch der Sondenabstand verändert, und das Potential V_1 geht dabei über in ein neues Potential $\tilde{V}_1$. Dadurch werden die Tiefen-

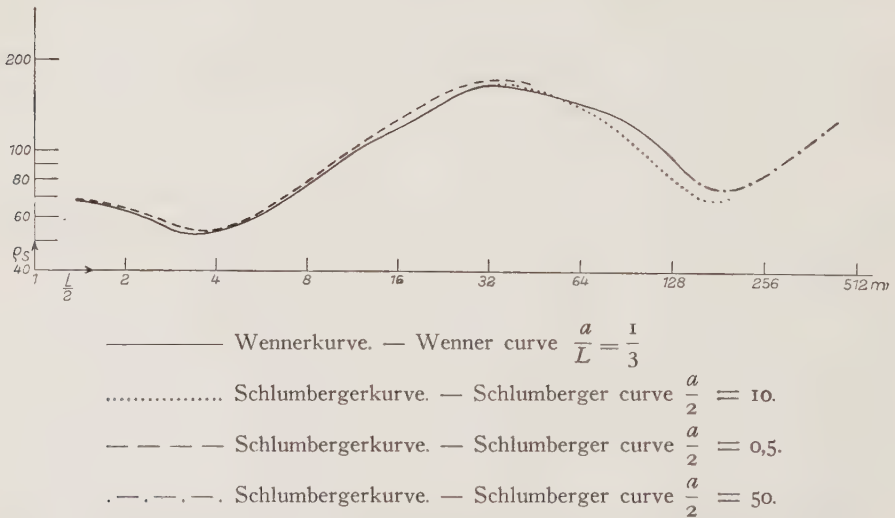


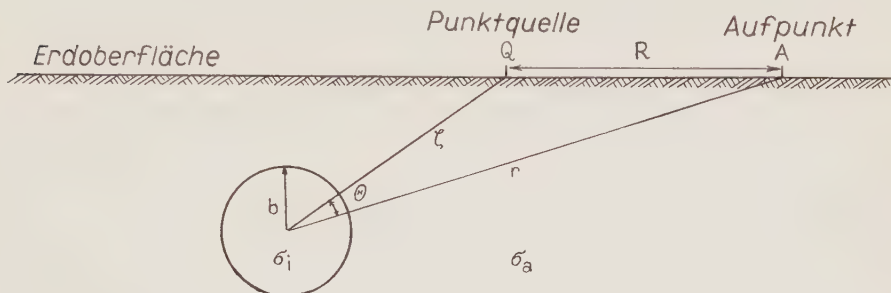
Abb. 5. Am gleichen Messpunkt aufgenommene Wenner- und Schlumbergerdiagramme. — Wenner and Schlumberger graph taken at the same location.

effekte zusätzlich gestört. Wie sich dies in Feldmessungen äussert, zeigt Abb. 5. Wennermessungen lassen sich demnach schwerer deuten.

Ähnliche Störungen machen sich auch bei Messungen in Schlumbergeranordnung bemerkbar, wenn der Sondenabstand vergrößert wird. Dies ist mit wachsender Elektrodenentfernung von Zeit zu Zeit nötig. Die dabei auftretenden Sondensprünge sind nicht allein auf die Änderungen von a/L zurückzuführen. Sie beruhen auch teilweise darauf, dass sich beim Umsetzen der Sonden die Potenzialfunktionen ändern. Wie man unter diesen Umständen die einzelnen

Kurvenzweige aneinanderfügen muss, sei an einem theoretischen Beispiel erläutert.

In homogenem Untergrunde befinde sich eine kugelförmige Inhomogenität (s. Abb. 6). Schlumberger- und Wennerdiagramm werden nach der aus Abb. 7 hervorgehenden Anordnung bestimmt.



Formel:

$$V(A) = \frac{I}{2\pi\sigma_a} \left[\frac{1}{R} + (\sigma_a - \sigma_i) \sum_{n=0}^{\infty} \frac{n}{\sigma_i n + \sigma_a (n+1)} \frac{b^{2n+1}}{\zeta^{n+1}} \frac{P_n(\cos \theta)}{r^{n+1}} \right]$$

$V(A)$ = Potential des Aufpunktes.

Df

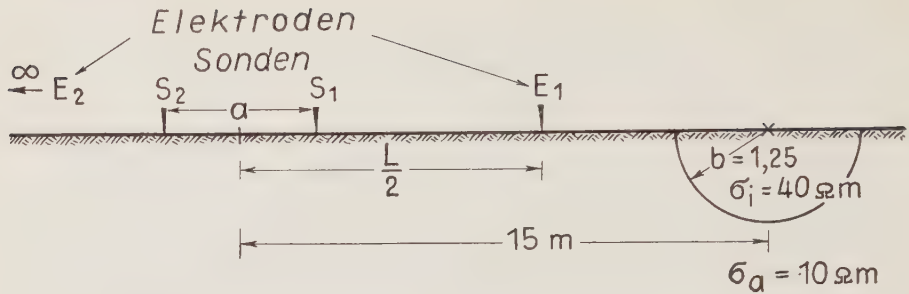
P_n = Kugelfunktion der Ordnung n .

Df

Abb. 6. Potential einer Punktquelle in einem homogenen, isotropen Halbraum mit kugelförmiger Inhomogenität. — Potential of a point source in a homogenous isotropic semi-infinite medium with spherical inhomogeneity.

Das Wennerdiagramm ist zweimal gestört. Das Schlumbergerdiagramm dagegen nur einmal. Beim Sondenabstand $a/2 = 13,75$ macht sich die Inhomogenität bei der Schlumbergeranordnung jedoch auch bemerkbar. Das zugehörige Kurvenstück liegt in einem zu hohen Niveau. Bei grösseren Elektrodenabständen, d.h. kleinen a/L , verläuft es mit grosser Genauigkeit parallel zur Idealkurve. Im Bereich $a/L > 0,25$ sind aber Abweichungen vom parallelen Verlauf zu beobachten. Der durch Inhomogenitäten verursachte Anteil des SONDENSprunges lässt sich also bei hinreichend kleinen Verhältnissen a/L durch eine Parallelverschiebung ausgleichen. Den durch Änderung von a/L verursachten Anteil des SONDENSprunges stellt man dazu mittels Gleichung (4) fest und kann dann weiter, nachdem man das neue Kurvenstück in die ideale Lage zum vorhergehenden gebracht hat, die Fortsetzung der Kurve $\rho^{(0)}(L/2)$ konstruieren. Sofern das Abstandsverhältnis a/L jedoch noch so gross ist, dass der Einfluss von Inhomogenitäten keine reine Parallelverschiebung bedingt, lassen sich Fehler nicht ganz vermeiden. Sie halten sich im allgemeinen aber in erträglichen Grenzen.

Anordnung:



Formel:

$$\rho = 2\pi \frac{\left(\frac{L}{2}\right)^2 \left(\frac{a}{2}\right)^2 \Delta V}{a I}$$

$$= \frac{I}{\sigma_a} \left\{ 1 + \frac{\left(\frac{L}{2}\right)^2 - \left(\frac{a}{2}\right)^2}{a} n \sum_{\sigma_i n + \sigma_a (n+1)} \frac{n}{\zeta^{n+1}} \left(\frac{P_n(\cos \theta_1)}{r_1^{n+1}} - \frac{P_n(\cos \theta_2)}{v_1^{n+1}} \right) \right\}$$

$$= 1 \text{ für } \frac{L}{2} < 15; \frac{a}{2} < 15$$

mit: $\cos \theta_1 = -1$ für $\frac{L}{2} > 15; \frac{a}{2} < 15$ $\cos \theta_2 = 1$ für $\frac{L}{2} < 15$

$$= 1 \text{ für } \frac{L}{2} > 15; \frac{a}{2} > 15$$

$$= -1 \text{ für } \frac{L}{2} > 15$$

Sondierungskurven:

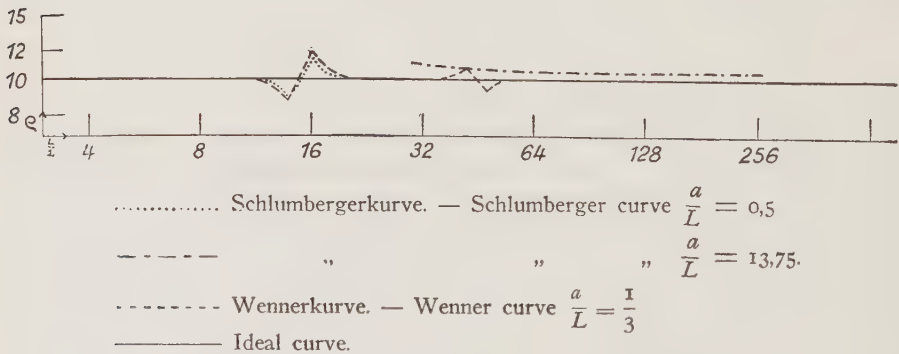


Abb. 7. Sondierungskurven bei homogenem Untergrund mit kugelförmiger Inhomogenität. — Resistivity curves in the case of a homogeneous subsurface with a spherical inhomogeneity.

DISCUSSION

H. DÜRBAUM: Which explanation may be given to the fact that in the Schlumberger-curve shown there are no disturbances at all, whereas such

appear in the Wenner-curve? According to your theoretical example one should expect that in such cases the Schlumbergercurve, too, is disturbed once.

K. DEPPERMAN: The inhomogenities of the subsoil, where the measuring curve has been taken, are different from those assumed in the theoretical example. Indeed, we know many practical examples for Schlumberger-curves, in which disturbances occur such as in the theoretical case.

SOME OBSERVATIONS ON SEISMIC WEATHERING CORRECTIONS

BY

O. KOEFOED *

ABSTRACT

When a rather extensive network of short distance refraction profiles was shot the following two observations were made. Firstly, the wave velocity in the weathered layer showed a quite considerable fluctuation in horizontal direction, the extreme values being of the order of 300 and 700 m/sec. A practical result of this scattering of the velocities is that an uncertainty of about 10% is introduced in the computation of the weathering corrections. The second observation is that, in the majority of cases, the travel time curve does not pass through the origin. It could be ascertained that this observation was not caused by errors in the method of observation. A probable explanation of the phenomenon is found in a theory that has been developed by Gassmann, who derived the velocity distribution for a hexagonal packing of spherical solid bodies. According to this theory extremely low velocities would occur in the first few centimeters of the crust of the earth. Qualitatively, our observations are in agreement with the theory of Gassmann.

In computing seismic weathering corrections the assumption is usually made that the velocity of the weathered layer remains constant. The computation procedure consists essentially of two steps: first the difference is determined between the observed first arrival time and the time that is required to travel the distance from the shotpoint to the seismometer at the velocity of the consolidated layer; next, this time difference is converted into the weathering correction by multiplying it by a factor

$$\frac{1}{2} \left(\frac{V_c - V_w}{V_c + V_w} \right)$$

where V_c denotes the velocity of the first consolidated layer and V_w that of the weathered layer. The value of this factor depends on the velocity of the weathered layer, and by keeping this factor constant in a given area we assume implicitly that the velocity of the weathered layer remains constant over this area.

In order to check the validity of the above assumption a rather extensive network of short distance refraction profiles was shot. These experiments were carried out in a diluvial area in the Netherlands. The surface formation consisted of sand mixed with various amounts of gravel. The boundary between the "weathered" layer and the "consolidated" layer coincides, in this area, with the water table.

The results that were obtained apply, of course, primarily to the area in which the experiments were carried out. Nevertheless, the fact that certain

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complications were observed points to the possibility that similar complications occur in other areas as well; thus the significance of the experiments may well be of a much more general nature.

Figure 1 shows one of the short distance refraction profiles that were obtained. Two interesting points are brought out by this profile: firstly, there is a quite considerable fluctuation of the velocity of the weathered layer in a

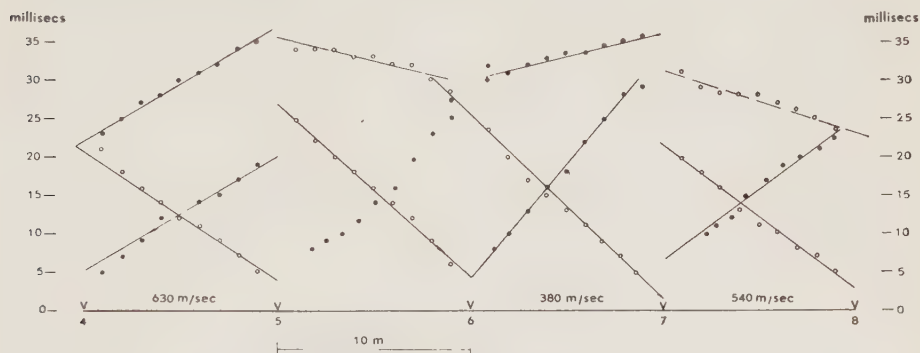
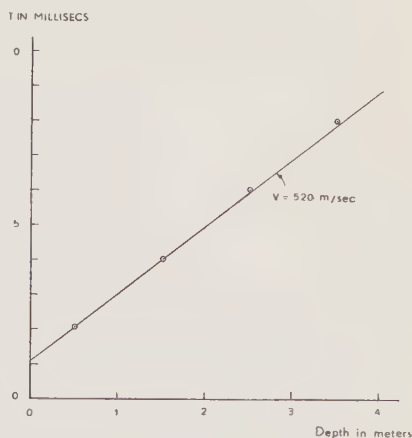
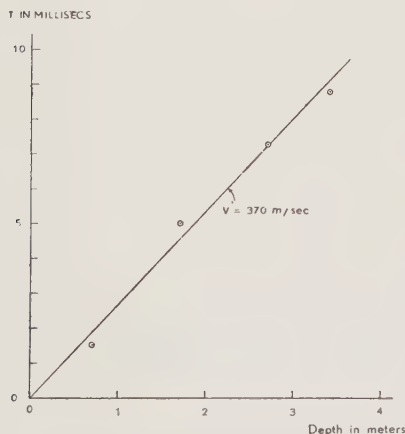


Fig. 1. Observed short distance refraction profile.

horizontal direction; secondly, it is seen that in the majority of cases the first segment of the travel time curve does not pass through the origin.

Let us first consider the fluctuation of the velocity of the weathered layer. It is well known that the slope of the first segment of the travel time curve may not represent the velocity of the weathered layer: the possibility must be considered that this segment corresponds to energy that is carried through a thin band of high velocity while the greater part of the weathered layer has a



Figs. 2. *a* and *b*. Observed vertical travel times compared with velocity according to short distance refraction.

lower velocity. In order to check this possibility on a number of points vertical velocity determinations have been made. In these vertical velocity determinations a number of seismometers was planted around a shothole and shots were fired in this hole at different depths. Care was taken to press the explosive charge as firmly as possible against the wall of the hole.

In all cases an excellent agreement was obtained between the vertical velocities and the velocities that were obtained from the short distance refraction profiles. Figures 2a and 2b give examples of this agreement. In these figures the circles are the points obtained in the vertical velocity determinations, and the drawn line gives the velocity that was obtained at the same locality from the short distance refraction profile.

The fluctuations of the velocity of the weathered layer thus appear to be real. For the two extreme values of this velocity on the profile of figure 1, 380 and 630 m/sec, the corresponding values of the multiplying factor

$$\sqrt{(V_c - V_{w}) / (V_c + V_{w})}$$

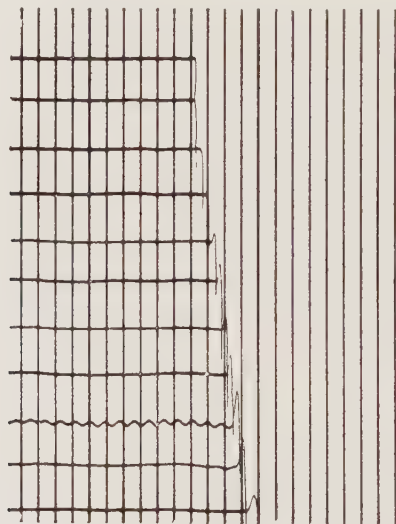
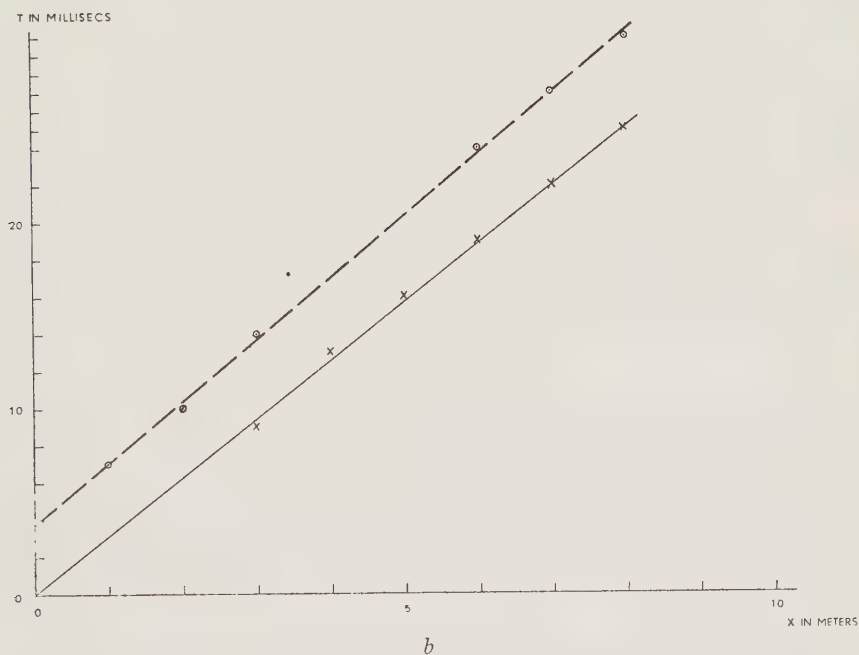
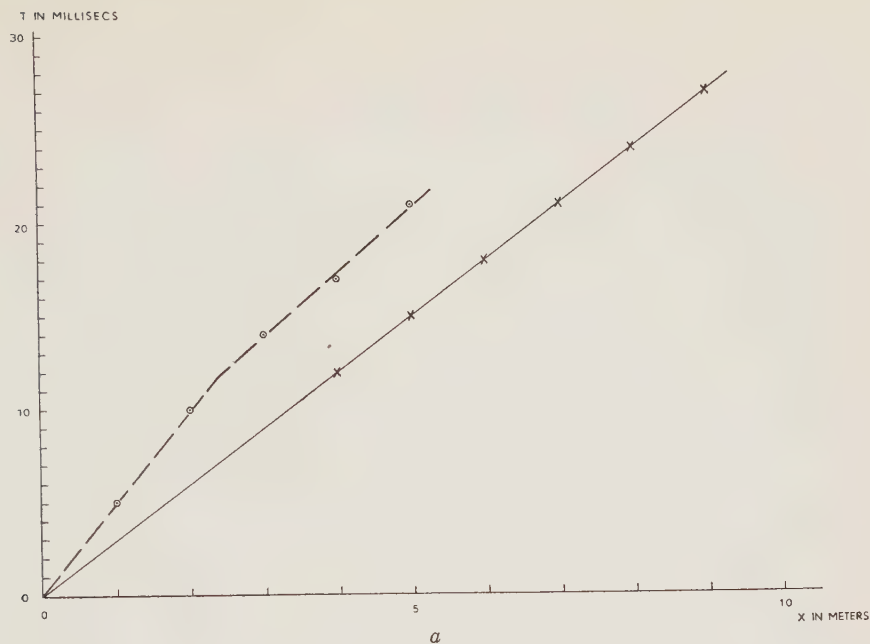


Fig. 3. Seismogram showing ground wave arrivals and air wave arrivals.

are 0.78 and 0.66 respectively. Fluctuations of this factor of this order of magnitude were found to be quite common in the test area. Since the value of the factor cannot be determined for each seismometer location separately, these fluctuations introduce an uncertainty of about 10 % in the values of the weathering corrections.

The second point that was noticed on the profile of figure 1 is the fact that as a rule the first segments of the travel time curves do not pass through the



Figs. 4. *a* and *b*. Travel time graphs of seismograms showing ground wave arrivals and air wave arrivals.

origin. Here again we must consider the possibility that this effect is due to inaccuracies in the method of observation. One could imagine that a time delay is introduced in the recording instruments, or that a time difference occurs between the moment of the explosion and the moment when the cap current is interrupted.

The possibility of these observational errors, however, is ruled out by the following observation. On some of the seismograms the sound wave was recorded as well as the ground wave. Contrary to the ground wave, the sound wave reaches the seismometers from above; consequently on the seismogram the sound wave will produce a kick in a direction opposite to that produced by the ground wave. An example of such a seismogram is shown in figure 3. On most of the traces a weak upward break (the sound wave) precedes the main downward kick that is produced by the ground wave. Figures 4a and 4b show two travel time curves obtained from this type of seismogram. In both figures the crosses indicate the arrivals of the sound wave and the circles those of the ground wave. To the arrival times of the sound waves a correction of -3 millisecs has been applied to account for the vertical travel time from the explosive charge up to the surface and from the surface down to the seismometer, a total vertical distance of 90 cm. It is seen that in both figures the T - X graph for the sound wave passes through the origin; the T - X graph for the ground wave passes through the origin in figure 4a but in figure 4b it has an intercept time of 4 millisecs. Obviously, then, this intercept time cannot be caused by observational errors.

It seems probable that the observed intercept times are connected with a theory that has been developed by F. Gassmann (Gassmann 1951). Gassmann derived the velocity distribution for a hexagonal packing of spherical solid bodies. He found in the first place that the velocity in the vertical direction differed from that in horizontal directions, a result that could be expected in view of the inherent anisotropy of the model. A more interesting result of Gassmann's investigation is that, both for the horizontal and for the vertical velocity, the velocity function is of the form

$$V = CZ^{1/6}$$

where V is the velocity, Z the depth and C a constant. The implication of this formula is that very close to the surface velocities occur of much lower values than are usually assumed by seismologists.

Field experiments by J. E. White and R. L. Sengbush (White and Sengbush 1953) showed no anisotropy but confirmed the general shape of the velocity function predicted by Gassmann. However, these experiments do not give a direct indication of the occurrence of very low velocities, the lowest velocity value published in their paper being 300 m/sec.

Figure 5 shows a computed refraction T - X graph for an isotropic velocity distribution

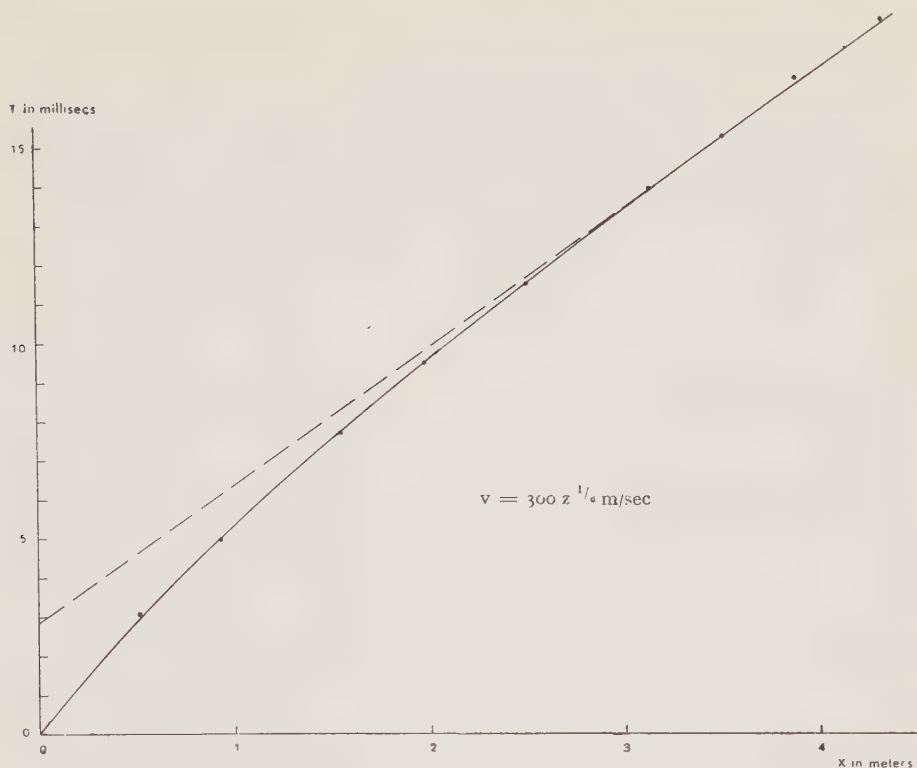


Fig. 5. Theoretical travel time curve for a velocity function according to Gassmann.

$$V = 300.Z^{1/6} \text{ m/sec.}$$

It is seen that, when obtained in field observations, such a T - X graph could easily be interpreted as a straight line intersecting the time axis 3 millisecs above the origin. In order of magnitude this agrees with our observations as shown in the profile of figure 1.

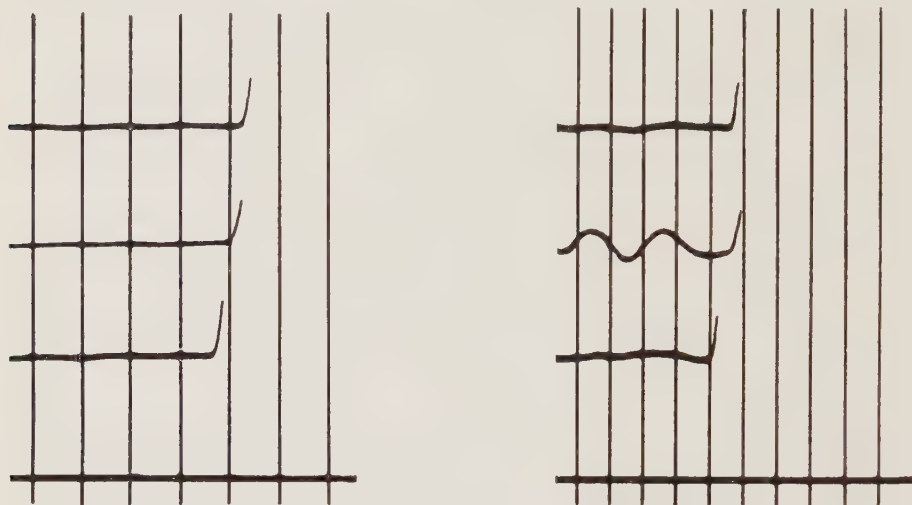
A further confirmation of the occurrence of these very low velocities was obtained by the following experiment. Three seismometers were planted in the normal manner at equal intervals along a straight line and a shot was fired. After the shot the seismometer in the middle was taken out of the seismometer hole, the bottom of the hole was filled with a layer of 5 to 10 cm of sand that was dropped in as loosely as possible and the seismometer was placed very carefully on top of this loose sand; the two outer seismometers were left unchanged and another shot was taken.

Figures 6a and 6b show the seismograms that were obtained with these two shots. As compared with the arrival times of the outer seismometers the arrival time of the middle seismometer is seen to be two or three millisecs later in the

second seismogram than in the first seismogram. This time delay corresponds to an average velocity in the layer of loose sand of 20 to 50 m/sec.

The above result is not in quantitative agreement with Gassmann's theory; according to Gassmann's formula the travel time through a layer of 10 cm would be 0.6 millisecon. On the other hand a quantitative agreement could hardly be expected, since Gassmann's theory is based on spheres in maximum close packing, whereas in our experiment the packing was made as loose as possible.

A practical conclusion from the above experiment is that poor planting of



Figs. 6. *a* and *b*. Portions of seismograms showing the effect of placing loose sand below the seismometer.

the seismometers, in addition to the other disadvantages involved, may increase the weathering correction appreciably.

The author is indebted to the N.V. De Bataafsche Petroleum My. for the opportunity to carry out the field experiments described in this paper and for the permission to publish the results.

REFERENCES

- GASSMANN F., 1951, Elastic Waves Through a Packing of Spheres. *Geophysics*, 16, 673-685.
 WHITE J. E. and SENGBUSH R. L., 1953, Velocity Measurements in Near-Surface Formations. *Geophysics*, 18, 54-69.

A REMARK CONCERNING THE PROBLEM OF HOW TO PLACE THE REFERENCE PLANE (DATUM LEVEL) IN REFLECTION SEISMIC PROSPECTING*

BY

T. KREY**

ABSTRACT

It has been shown in a paper by L. Y. Faust that the wave velocity in rock depends on the depth below the ground surface according to a specified equation. It follows that the attitude of the planes of equal velocity is influenced by the topographic relief. Under these conditions the problem arises of how to place the reference plane in such a manner, that the fluctuations of the planes of equal velocity, that result from the fluctuations in the topography, shall not affect the results of the depth computations. In the present paper an analytical solution of this problem is given.

Before plotting the horizons in reflection seismic prospecting using certain time-depth curves (e.g. such as those based on linear velocity increase) the observed data are generally reduced to a reference plane or datum level (see DIX, 1952). But here the problem arises of how the placing of the reference plane may best be carried out. Have we to assume a uniform plane, parallel to the sea level, or a plane parallel to the ground surface in cases of topographic relief (Tralls and Mossman, 1952)?

In a paper recently published in Geophysics (Faust, 1951) it has been shown that the wave velocity in rocks of the same age and also of the same lithologic nature depends on $\frac{1}{6}$ th power of its depth below ground surface. Planes of equal velocity are therefore to be expected to have a certain relationship to the topographic relief. Consequently, it would be wrong to assume a uniform level for the reference plane. It would, however, also be wrong to place the reference plane roughly parallel to the ground surface. As to this reference is made to the article by Tralls and Mossman (1952).

Now, under certain assumptions which, however, represent a considerable idealization, certain statements may be made from a theoretical point of view on the most favourable position of the reference plane. Let z be the depth below sea level; x and y the horizontal orthogonal coordinates; $h(x, y)$ the elevation above sea level; $\tau(x, y, z)$ the geological age of the rock; a, b and α certain rock constants; and $v(x, y, z)$ the local velocity of the compressional

* Parts of this paper have been presented at the Geophysical Colloquium of the University of Göttingen, February 13th 1954.

** Seismos G.m.b.H., Hanover.

wave. In addition, it will be assumed that, roughly, the lithologic nature of the strata does not vary. Then we have according to Faust (1951).

$$v = (\alpha + \tau)^{\frac{1}{6}} \cdot (b + z + h(x, y))^{\frac{1}{6}}; \quad . \quad . \quad . \quad (1)$$

for it is shown by him that the wave velocity in rocks of varying age, lying at the same depth and being of uniform lithologic nature, depends on the geological age to $\frac{1}{6}$ th-power, the relationship between velocity and depth below ground surface having already been mentioned (also $\frac{1}{6}$ th-power). In eq. (1) a constant multiplication factor has been omitted.

It may now be assumed that, roughly, τ depends on z in the following simple way

$$(\alpha + \tau) = (a + z)^p. \quad . \quad . \quad . \quad . \quad (2)$$

Here, too, a constant multiplication factor has been omitted. In equations (1) and (2), α , a and b are of relatively small magnitude. In the article by Faust these terms have therefore not been mentioned. Equation (2) implies that the elevation of the surface is independent of the geologic nature of the deeper strata, which to a large extent should be the case in many areas, e.g. in those covered by diluvium or in others which have undergone a period of strong erosion. In addition, the assumption is involved in eq. (2) that the strata overlying the reflecting horizon of interest are in a horizontal position.

To obtain correct results the assertion will now be made that for the construction of reflections the reference plane must be placed at the height $h/(p+1)$.

In order to prove this, powers of higher order than the first in h and $(a-b)$ will be neglected. According to equations (1) and (2) we have

$$v(x, y, z) = (a + z)^{\frac{1}{6}p} \cdot (b + z + h(x, y))^{\frac{1}{6}}. \quad . \quad . \quad . \quad (3)$$

It has now to be shown that the travel time along a vertical ray which, for $h=0$, extends from sea level down to the depth z will be equal to the time required on a corresponding ray which, for $h \neq 0$, extends from $h/(p+1)$ to the depth $\{z - h/(p+1)\}$, i.e. the following relation has to be proved:

$$\int_0^z (a + \zeta)^{-\frac{1}{6}p} (b + \zeta)^{-\frac{1}{6}} d\zeta - \int_{\frac{h}{p+1}}^{z - \frac{h}{p+1}} (a + \zeta)^{-\frac{1}{6}p} (b + \zeta + h)^{-\frac{1}{6}} d\zeta = A(h) = O(h) \quad (4)$$

Replacing in the second integral ζ by $\{\xi - h/(p+1)\}$ and in the first integral ζ by ξ , and expanding in a power series in h we have

$$A(h) = -h \frac{d}{dh} \left[\int_0^z \left(a + \xi - \frac{h}{p+1} \right)^{-\frac{1}{6}p} \left(b + \xi + \frac{ph}{p+1} \right)^{-\frac{1}{6}} d\xi \right] + h^2 \dots + \dots \quad (5)$$

After differentiation and an easily carried out transformation eq. (5) becomes

$$A(h) = -\frac{h}{6}(b-a) \frac{p}{p+1} \int_0^z \frac{(a+\xi)^{-\frac{1}{6}p} (b+\xi)^{-\frac{1}{6}}}{(a+\xi)(b+\xi)} d\xi + h^2 \dots + \dots \quad (6)$$

But on the right side there are only terms of higher order than the first in h and $(a-b)$ and thus the above assertion is evidently correct.

The case, $p = 1$, will probably be of special interest, i.e. uniform sedimentation according to eq. (2). In this case we have $1/(p+1) = \frac{1}{2}$, i.e. the reference plane would have to be placed in such a way that its configuration will conform to, and amount to 50 percent of, the variations of the topographical elevations. This theoretical result is in good agreement with the conditions described by Tralls and Mossman (1952) at the top of page 227.

It is quite imaginable that other values of p may also be important. For instance, $p < 1$ would have to be chosen for a sedimentation which has continuously increased up to the present, and $p > 1$ would hold for a sedimentation which has continuously decreased.

There are also other cases which may be expressed by equation (1). When, for instance, the topographical conditions are due purely to young tectonic movements, so that the ground surface is parallel to the strata at a greater depth, we can write $\tau = f(z + h(x, y))$, and consequently $v = v(z + h(x, y))$. In this case the reference plane would have to be placed parallel to the ground surface. When the topographic features of the ground surface as generated by recent tectonic forces have already been levelled out by lateral erosion to the fraction $\frac{1}{q}$ we have

$$\tau = f(z + qh(x, y))$$

In the special case of $(\alpha + \tau) = (a + z + qh(x, y))^p$ the reference plane has to be placed at the height $\mu \cdot h$, wherein $\mu = \frac{pq+1}{p+1}$. Then the analogue to eq. (4) will be

$$A_1(h) = \int_0^z (a+\zeta)^{-\frac{1}{6}p} (b+\zeta)^{-\frac{1}{6}} d\zeta - \int_{-\mu h}^{z-\mu h} (a+\zeta+qh)^{-\frac{1}{6}p} (b+\zeta+h)^{-\frac{1}{6}} d\zeta = 0 \quad (4a)$$

Analogous to equations (5) and (6) the following equations hold

$$A_1(h) = -h \frac{d}{dh} \left[\int_0^z (a+\xi + (q-\mu)h)^{-\frac{1}{6}p} (b+\xi + (1-\mu)h)^{-\frac{1}{6}} d\xi \right] + h^2 \dots \quad (5a)$$

and

$$A_1(h) = -\frac{h}{6}(b(q-\mu)p + a(1-\mu)) \int_0^z \frac{(a+\xi)^{-\frac{1}{6}p} (b+\xi)^{-\frac{1}{6}}}{(a+\xi)(b+\xi)} d\xi + h^2 \dots \quad (6a)$$

It has, however, now to be assumed that not only terms such as $h(b-a)$ but also terms such as $h \cdot b$ and $h \cdot a$ can be neglected. In the case of $p = 1$ we have

$$\mu = (q + r) / 2.$$

If only half the amount should have been removed by erosion we would have

$$q = 2 \text{ and } \mu = \frac{3}{2}.$$

In actually placing the reference plane we may take account of the preceding mathematical conclusions especially when dealing with an area where rather exact results are desired. But we have still to think of another problem. Sudden and abrupt variations in the elevations of the surface will produce only gradual variations in the planes of equal velocity at greater depths. Obviously this fact will produce certain deviations of the best reference plane from the theoretical results given in this paper. No further comment will here be made as to the calculation of such deviations. Perhaps the author will report on this problem at a later date.

The author is indebted to Seismos G.m.b.H. for permission to publish this paper and to Mr. Tüchel for the translation into English.

REFERENCES

- DIX, C. H., 1952, Seismic Prospecting for Oil, 73-106, Harper and Brothers.
 FAUST, L. Y., 1951, Seismic Velocity as a Function of Depth and Geologic Time, Geophysics, 16, 192-206.
 TRALLS, H. M. and MOSSMAN, R. W., 1952, Relation of Seismic Corrections to Surface Geology, Geophysics, 17, 218-228.

SOME REMARKS ON THE ERRORS IN THE CALCULATION OF THE VERTICAL GRADIENT OF GRAVITY *

BY

V. BARANOV ** AND J. TASSENCOURT **

ABSTRACT

In a previous paper by the first author a method has been presented for computing the first vertical derivative of the gravity field or of the magnetic field. In the present paper an analysis is given of the errors in the first vertical derivative that result when the latter is computed by the above method. Two sorts of errors are considered. Firstly, the error in the first vertical derivative that results from the errors in interpolating between isogam lines on the Bouguer anomaly map. Secondly, the error in the first vertical derivative that results from the approximations upon which the computation method is based. The conclusion is reached that both sorts of error are only of minor importance.

This paper is a reply to a question asked by Mr. Thomas A. Elkins from Mr. V. Baranov. Mr. T. A. Elkins writes:

"Your vertical gradient paper (Baranov, 1953) describes an ingenious method of treating some important but difficult problems. I would have been interested in your including a mathematical discussion, if such is practical, of the effect of the approximation of the curve by pieces of biquadratic parabolas on the accuracy of final formulas".

This question may possibly be of general interest and it might be useful to express our ideas on the subject. The method of calculation employed requires two stages:

- 1) Plotting of canonical values on the gravimetric map,
- 2) Calculating the product of each of these values by a coefficient and adding all these products.

The possible errors are naturally divided into two groups:

- 1) Errors of plotting due to necessary interpolation in the reading of each canonical value,
- 2) Errors in the calculation of the coefficients.

The two sources of errors are independent and will be dealt with separately.

I. PLOTTING ERRORS

The Bouguer anomaly map is the basic datum for the transformation and we accept the accuracy of isogams. Errors may occur when reading on this map

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** Compagnie Générale de Géophysique, Paris.

the value corresponding to each corner of the unit spaced grid. This error will be called e . Experience shows that the error of interpolation is not greater than a tenth of the interval between two neighbouring isogams. The first integration (with respect to the polar angle ω) is simply an average of the values which are all plotted on the same circle. The mean value $\bar{g}(\rho)$ which will be used in the second integration has therefore the same error e divided by the square root of the number of points entering into the average. Consequently, there are for the center and for each of the circles the errors

$$e, \quad \frac{e}{2}, \quad \frac{e}{2}, \quad \frac{e}{\sqrt{8}}, \quad \frac{e}{\sqrt{8}}, \quad \frac{e}{\sqrt{12}}, \quad \frac{e}{\sqrt{12}}, \quad \frac{e}{4}, \quad \frac{e}{4}, \quad \frac{e}{4}$$

When integrating with respect to ρ , the errors will be multiplied by the coefficients. In the case of the first derivative the error in the sum of the products is then equal to 3.5 Eötvös units.

Furthermore, to obtain the vertical gradient in Eötvös units, we have to multiply the result by $10,000/\alpha$ where α is the length in meters of the grid spacing. For instance, if $\alpha = 2000$ m (most commonly employed spacing), and if 1 milligal is the contour interval, we shall have an error of

$$0.1 \times 3.5 \times \frac{10000}{2000} = 1.75 \text{ Eötvös units}$$

Such maximum error is admissible as contours are usually traced with 10 Eötvös units interval. In a more detailed study the interval of the isogams is brought down to 0.2 milligal; the error will then be reduced to 0.35 E.U. It must be observed that this error does not depend on the method of the integration with respect to ρ .

2. DETERMINATION OF COEFFICIENTS

It is known that the calculation of the first derivative of the gravimetric field is based on an integration with respect to ρ of the function

$$\bar{g}(\rho) \frac{z \rho}{(\rho^2 + z^2)^{3/2}}$$

Now, the experimental radial curve $\bar{g}(\rho)$ is approximated in our method by a series of arcs of biquadratic parabolas. The arcs are bounded by the radii of the canonical circles and coincide with the experimental curve at the end of each interval. We propose to estimate an upper limit of the error due to the substitution of these parabolas for the actual curve. The procedure will be inspired by the classical demonstrations which can be found, for example, in the treatise "Finite Differences" by Tomlinson Fort (1948).

Let us consider first an arbitrary but continuous function $f(x)$ the value of which is known for the three abscissae x_1, x_2, x_3 . We can write

$$f(x) = A + Bx + Cx^2 + R(x)$$

The coefficients A , B and C are determined by the given values of the function, while the remainder $R(x)$ vanishes for each of these three abscissae. We consider now an auxiliary function

$$\varphi(x) = f(x) - A - Bx - Cx^2 - M. (x - x_1) (x - x_2) (x - x_3)$$

where M is a constant. Obviously $\varphi(x)$ admits the same three roots, but we can determine the constant M so that $\varphi(x)$ has a fourth root, say $\bar{x}$. It is then known that if a continuous function has four roots in any interval, the third derivative of this function will have at least one root in the same interval. Calling ξ the zero of $\varphi'''(x)$ and differentiating three times we get

$$\varphi'''(\xi) = f'''(\xi) - 6. M = 0$$

and hence

$$M = \frac{1}{6} f'''(\xi)$$

Now, the value of the fourth root is arbitrary. Consequently, replacing $\bar{x}$ by x and M by its expression we get

$$f(x) = A + Bx + Cx^2 + \frac{1}{6} (x - x_1) (x - x_2) (x - x_3) f'''(\xi)$$

To use this general formula for our purposes, let us put $f = \bar{g}$ and $x = \frac{\rho^2}{\alpha^2}$, where α is the length of the grid spacing. It becomes

$$\frac{d^3 \bar{g}}{d\bar{x}^3} = \alpha^6 D^{(3)}$$

$$\bar{g}(\rho) = A + B\rho^2 + C\rho^4 + \frac{1}{6}(\rho^2 - \rho_1^2) (\rho^2 - \rho_2^2) (\rho^2 - \rho_3^2) D^{(3)}(\xi)$$

where $D^{(3)}$ is the third derivative of $\bar{g}$ with respect to ρ^2 and ξ is some function of ρ .

This is indeed a correct expression of the function $\bar{g}(\rho)$ in the interval (ρ_1, ρ_3) . Now, if we match the actual curve to the biquadratic parabola

$$A + B\rho^2 + C\rho^4$$

we neglect the fourth term

$$R(\rho) = \frac{1}{6} (\rho^2 - \rho_1^2) (\rho^2 - \rho_2^2) (\rho^2 - \rho_3^2) D^{(3)}$$

and this is the error we make. Of course, the value of $D^{(3)}$ is unknown, but we shall obtain obviously an upper limit of this error if we replace this derivative by the maximum D_m of its absolute value. Thus, the maximum error will be

$$R_m(\rho) = \frac{1}{6} D_m. (\rho^2 - \rho_1^2) (\rho^2 - \rho_2^2) (\rho^2 - \rho_3^2)$$

Finally, it is clear that the actual experimental curve $\bar{g}(\rho)$, in other words the actual anomaly, can be considered as a sum of the anomaly approximated by the arcs of biquadratic parabolas and a small residual anomaly $R(\rho)$ which is smaller than $R_m(\rho)$ in absolute value. This residual anomaly is neglected when calculating the vertical gradient. Now, to appreciate the error we must consider

separately this additional anomaly and calculate its contribution to the vertical gradient. For this purpose we have to integrate

$$\int_0^{\infty} R_m(\rho) \cdot \frac{z\rho d\rho}{(\rho^2 + z^2)^{3/2}}$$

after replacing $R_m(\rho)$ by its expression, then differentiate the result with respect to z and, finally, to put $z = 0$. All these operations are a little tedious but very easy to perform. We arrive at the formula

$$E = \frac{1}{a} (0,267.D_1 + 0,008.D_2 + 0,136.D_3 + \dots)$$

where D_k is the maximum absolute value of the third derivative with respect to ρ^2 of the function $\bar{g}$ in the k -th canonical interval. The factor $\frac{1}{a}$ appears during the differentiation with respect to z . The third derivative decreases in practice always very rapidly. The coefficient of the second term being small we may retain only the first term. Thus, the maximum error is smaller than

$$E = 0,267 \cdot \frac{D_1}{a} = \frac{4}{15} \frac{D_1}{a}$$

SOME EXAMPLES

To give a practical idea of this error we shall take the case of a sphere of excess mass m , its center being at the depth h under the plane of measurements. As unit of length let us take the length of the grid spacing a . The formula of the gravity anomaly is

$$g = \frac{fm}{a^2} \frac{h}{(\rho^2 + h^2)^{3/2}}$$

Hence, for $\rho = 0$, the maximum vertical gradient is

$$-g'_{max} = \frac{2 fm}{a^3} \left(\frac{1}{h}\right)^3$$

The maximum D of the third derivative with respect to ρ^2 is easily found to be

$$D = \frac{105}{8} \frac{fm}{a^2} \left(\frac{1}{h}\right)^8$$

Thus, the maximum error is

$$E = \frac{4}{15} D = \frac{7}{2} fm \left(\frac{1}{h}\right)^8$$

The ratio of this main error to the exact value of the gradient will be

$$\frac{E}{-g'_m} = \frac{7}{4} \cdot \left(\frac{1}{h}\right)^5$$

For $h = 2$ (example given in the paper presented in Hanover, Baranov 1953) we obtain the upper limit 5,5 %.

Of course, the actual error is smaller: it is only 2,1 %. The error decreases rapidly, when h increases. As a matter of fact the radial curve then becomes very flat and the value of the third derivative becomes small.

Let us consider now the sphere taken as an example by Thomas A. Elkins (1951). If $h = 15,000$ feet $\approx 4,500$ m, the maximum value of the gravity is 1,5 milligal and that of the vertical gradient is 6,7 E.U. If the calculation of the vertical gradient is carried out with a grid of $\alpha = 2,250$ m spacing, the upper limit of the error will be

$$E = 6,7 \times \frac{5,5}{100} = 0,4 \text{ E.U.}$$

REFERENCES

- BARANOV, V., 1953, Calcul du Gradient Vertical du Champ de Gravité ou du Champ Magnetique Mesuré a la Surface du Sol, *Geophysical Prospecting*, 1, 171-191.
- ELKINS, T. A., 1951, The Second Derivative Method of Gravity Interpretation, *Geophysics*, 16, 29-50.
- TOMLINSON FORT, 1948, *Finite Differences and Difference Equations in the Real Domain*, Oxford Clarendon Press.

ROLE JOUÉ PAR LA CORRECTION LUNI-SOLAIRE EN PROSPECTION GRAVIMÉTRIQUE *

PAR

R. NEUMANN **

ABSTRACT

The luni-solar corrections are considered under the three following aspects:

Quality of results: the application of tidal corrections to all stations is pointless as long as the operations do not substantially exceed two hours.

Working conditions: it seems possible to increase the duration of programs without any loss of precision, but operating in such a way requires particular care.

Behaviour of gravity meters: the introduction of tidal corrections allows to separate three kinds of instrumental drifts; a good knowledge of the mean operational drift enables to appreciate the quality of a given set of measurements.

An example is given to show the possibility in some cases to detect small errors which are close to the limit of precision of the instrument.

Les membres de l'E.A.E.G. ont tous reçu dernièrement un supplément au „Geophysical Prospecting” contenant une table de prédiction de la correction gravimétrique luni-solaire ($L-S$), présentée par M. Goguel. Cette brochure était accompagnée d'un questionnaire relatif à son utilisation pratique.

Il nous a paru intéressant, à cette occasion, d'analyser quelques aspects pratiques de cette correction et d'en dégager certaines conséquences relatives à son application à la prospection courante.

INTÉRÊT DE LA CORRECTION LUNI-SOLAIRE

Nous rappellerons brièvement en quoi consiste un programme classique de mesures de gravité, pour préciser de quelle façon s'introduit la correction $L-S$ (figure 1):

on stationne d'abord un point A , appelé base, où la valeur de la gravité est connue, et l'on y effectue une lecture sur le cadran gradué du gravimètre (dans le cas présent un „North American”), en notant l'instant de l'observation;

on stationne ensuite aux points $1, 2, 3, \dots, n$, pour lesquels on note également la lecture faite sur le cadran et l'heure;

on termine par une station connue, la base B (ou à nouveau A).

* Presented at the Copenhagen Meeting of the European Association of Exploration Geophysicists, May 19/22, 1954.

** Compagnie Générale de Géophysique.

Au bureau, on commence par convertir les divisions du cadran en milligals, en multipliant les lectures faites par le coefficient d'étalonnage du gravimètre, puis l'on affecte aux valeurs ainsi obtenues la correction $L-S$ extraite d'une table.

Les observations faites en A et B permettent de transformer ces lectures

Mission G.342			Opérateur DUPONT			Grav. 45 h 0,9133		Date 26/6/53		N°			
St.	Base	Heure	T minutes	Lecture ℓ	Milligal L=ℓ×h	L.S	Différence	Dérive	Valeur g	Obs.			
1 2 3	A	11 ^h 25	28	27,96	25,53	+16	573,08	0	<u>598,77</u>				
		11 ^h 30		27,94									
		11 ^h 53	25	39,05	35,66	+16	573,08	0	608,90				
		11 ^h 58	30	29,15	26,62	+16		-1	599,85				
		12 ^h 04	36	19,73	18,02	+16		-1	591,25				
.....													
II	B	12 ^h 52	84	20,26	18,50	+14	573,08	-1	591,71				
.....													
		13 ^h 20	22	9,51	8,69	+13		-2	<u>581,88</u>				
		13 ^h 23		9,51									
													

Fig. 1. Feuille de mesures gravimétriques. — Gravity observation form.

corrigées (qui ne sont en fait que des mesures de Δg) en valeurs de g , que l'on calcule en tenant compte d'une répartition, linéaire en fonction du temps, de la dérive observée entre les instants T_A et T_B *.

On sait, en effet, qu'une lecture au gravimètre faite en un même emplacement, et corrigée de l'influence $L-S$, ne garde pas une valeur constante dans le temps; les causes principales de cette évolution sont essentiellement:

l'influence du vieillissement des ressorts constituant la partie essentielle du gravimètre;

les légers chocs provoqués par le transport et les mises en station successives;

les faibles variations de température qui interviennent même si l'appareil est soigneusement calorifugé.

Faute de pouvoir connaître l'allure exacte de cette dérive, on admet qu'elle est *linéaire* dans un intervalle de temps assez court, et on la détermine, sous forme de ligne brisée, par des passages aux bases aussi fréquents que possible.

* En réalité, toutes les colonnes de la figure 1 ne sont pas remplies, car les calculs se font à la machine qui se charge des multiplications et interpolations nécessaires.

La figure 2 illustre de manière schématique le rôle des différents éléments qui interviennent dans la détermination des valeurs de g , ainsi que la part d'erreur provenant de chacun d'eux.

La partie supérieure de la figure représente le dépouillement graphique d'une station S , dans un programme de mesures réalisé entre les bases A et B ; la

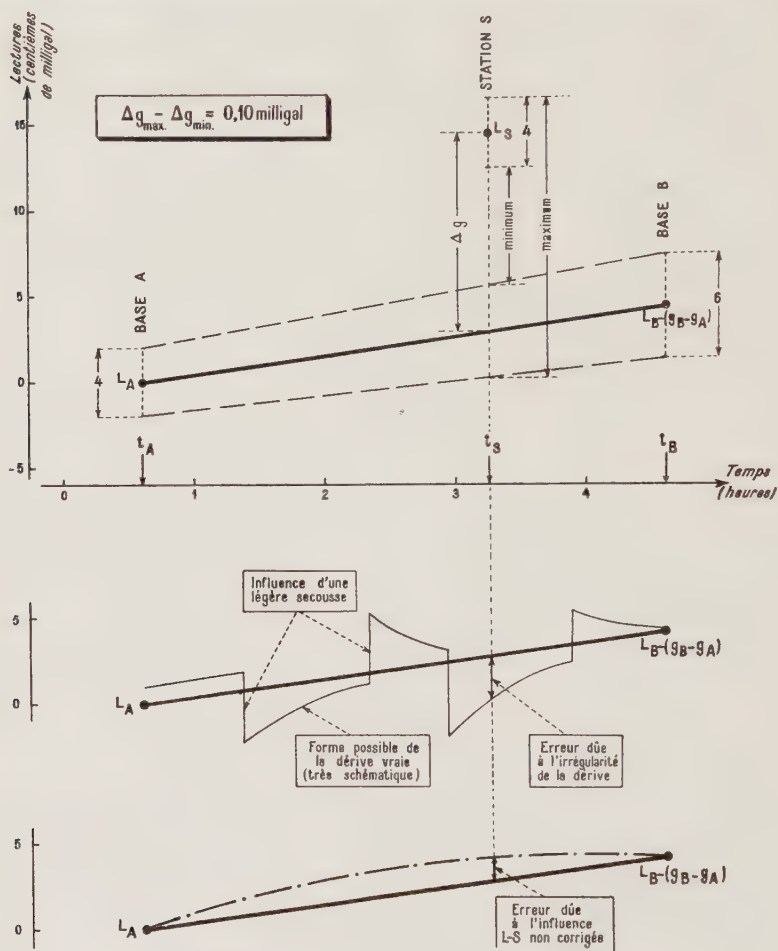


Fig. 2. Causes d'erreurs. — Causes of errors.

mesure en A , c'est-à-dire la lecture corrigée de l'étalonnage, est supposée égale à O , et la mesure en B est ramenée à celle que l'on aurait observée en A au même instant, c'est-à-dire $L_B - (g_B - g_A)$; la différence $g_B - g_A$ est connue: elle résulte de l'exécution, antérieure aux mesures de stations, d'un réseau de bases reliées directement entre elles, réseau compensé par la méthode des moindres carrés. Entre la station S et la base A , on a mesuré une diffé-

rence Δg qui tient compte de la dérive, répartie *linéairement* entre les points A et B .

En réalité, la *position* des différents points du graphique n'est connue qu'à une certaine approximation près, qui correspond à l'*erreur de lecture*, à laquelle s'ajoute, dans le cas du point B , l'erreur sur la différence $g_A - g_B$; nous avons matérialisé les valeurs moyennes de ces erreurs par des segments parallèles à l'axe des ordonnées. On voit que si l'on considère les positions limites que peut prendre la dérive en fonction de la longueur donnée à ces segments, on peut observer une différence de 0,10 milligal entre les valeurs extrêmes de Δg ; cet écart, évidemment proche de l'erreur maxima, ne caractérise pas la précision moyenne des mesures de g qui, nous le verrons, reste habituellement comprise entre 3 et 4 centièmes de milligal.

Au milieu de la figure, on a représenté une forme possible (très schématique) de la dérive vraie; cette représentation tient compte du phénomène suivant, qui est maintenant assez bien connu: chaque petit choc subi par l'instrument se traduit par un déplacement de l'échelle (de quelques centièmes seulement lorsqu'il s'agit de secousses normales) après lequel la dérive tend asymptotiquement vers une pente régulière. Ce phénomène introduit sur les valeurs de Δg une erreur supplémentaire, dont la valeur moyenne est d'ailleurs accessible: en effet, la connaissance des erreurs sur la position des points A , B et S permet de dégager l'erreur moyenne e_1 commise sur Δg en supposant la dérive rectiligne; or, la statistique des mesures reprises conduit à une erreur moyenne e_2 supérieure à e_1 ; on a donc

$$e_2^2 - e_1^2 = \varepsilon^2$$

expression dans laquelle ε représente l'écart moyen entre la dérive vraie et la dérive rectiligne. ε est en général du même ordre de grandeur que l'erreur de lecture (2 centièmes).

Le rôle essentiel de la correction $L-S$ apparaît clairement sur la partie inférieure de la figure; cette correction permet, en effet, de dégager de la dérive un *élément non-linéaire*. Il est évident, d'après ce qui vient d'être exposé, qu'il y aurait intérêt à tracer la forme vraie de la dérive; la droite n'est qu'une approximation grossière, qui traduit notre impuissance à serrer de plus près un phénomène mal connu. C'est pourquoi tout élément concourant à améliorer notre connaissance à ce sujet doit être considéré a priori comme intéressant.

Remarquons encore que, dans le mode opératoire que nous venons de décrire, la valeur absolue de l'influence $L-S$, et même son amplitude totale, ne jouent aucun rôle; le seul élément important ici est la non-linéarité. Il existe d'autres procédés de mesures de g pour lesquels il est indispensable d'utiliser les valeurs absolues de la correction; par exemple, certains travaux de grande reconnaissance, ne nécessitant pas une grande précision, peuvent être accomplis en ne stationnant aux bases qu'à des intervalles de plusieurs jours; l'application de la correction $L-S$ conduit dans ce cas à une amélioration sensible de la qualité des mesures. Nous nous limiterons dans cet exposé à la prospection gravi-

métrique du type le plus courant, c'est-à-dire comportant plusieurs passages aux bases dans la journée, les mesures étant faites à l'aide d'un seul gravimètre.

Il était normal d'appliquer pendant un certain temps la correction $L-S$ à des programmes réalisés dans les conditions habituelles, c'est-à-dire pour lesquels la périodicité des retours aux bases avait été fixée à environ deux heures. Nous vérifierons un peu plus loin que cet intervalle de temps, compte tenu des appareils utilisés, était tout à fait convenable, et conduisait à des déterminations „industrielles” des valeurs de g d'une précision suffisante pour les besoins d'une étude détaillée.

Avec l'introduction de la correction $L-S$, on pouvait se demander, d'une part, si cette correction s'avérait réellement *efficace*, autrement dit si la précision des résultats était améliorée, d'autre part, si sa mise en œuvre ne permettait pas d'allonger la durée des programmes sans perte sensible de précision.

Ce dernier point suppose que l'on a pu analyser le comportement d'un gravimètre à partir de l'observation de sa dérive, et déterminer la durée maxima pendant laquelle cette dérive peut être considérée comme linéaire.

INFLUENCE SUR LA QUALITÉ DES RÉSULTATS

La figure 3 présente la courbe de l'influence $L-S$ calculée pour la latitude de Paris le 10 Juin 1953; il s'agit de la variation la plus ample relevée à cette latitude pour l'année 1953: 0,25 milligal en 9 heures environ. Il peut sembler évident que l'on doit tenir compte d'une telle variation lorsque l'on effectue des mesures dont la précision doit rester inférieure à 4 centièmes de milligal; mais nous venons de voir que la correction qui intervient en fait est seulement la mesure de l'écart entre la *courbe vraie* et la *droite* joignant les valeurs extrêmes observées entre deux instants T_A et T_B .

Nous avons fait ressortir quelques valeurs maxima de cet écart en fonction du temps: de 0,01 en 2 heures, il devient 0,05 en 4 heures, pour atteindre 0,25 en 17 heures. La valeur 0,01 milligal en deux heures est à rapprocher de l'amplitude que l'on peut observer dans le même temps: 0.09 mgal.

On voit donc que pour un programme de mesures d'une durée de l'ordre de 2 heures, le fait de négliger la correction $L-S$ conduit à introduire une *erreur maxima d'un centième sur quelques stations centrales*; cette erreur peut être considérée comme *absolument négligeable*, puisqu'elle affecte des mesures dont la précision (3 ou 4 centièmes) dépend, nous l'avons vu, de beaucoup d'autres facteurs. On doit donc en conclure qu'il est inutile d'effectuer cette correction tant que la durée du programme ne dépasse pas nettement deux heures, et nous trouvons là une justification a posteriori du choix de cet intervalle de temps pour la périodicité des retours aux bases.

La connaissance de l'amplitude totale de l'effet $L-S$ joue cependant un rôle: ayant observé une certaine dérive expérimentale, il est nécessaire d'en dégager la part qui revient à cet effet, pour pouvoir juger si les mesures sont accep-

tables. Une dérive observée de 0,20 en 2 heures peut, corrigée, devenir 0,11, mais inversement un 0,08 peut se transformer en un 0,17: dans ces conditions, il faudrait plutôt contrôler le second programme que le premier. Toutefois, un tel contrôle étant réalisé, il n'est pas indispensable de calculer la correction pour toutes les stations.

Un calcul approché a permis de généraliser ce qui précède et de déterminer

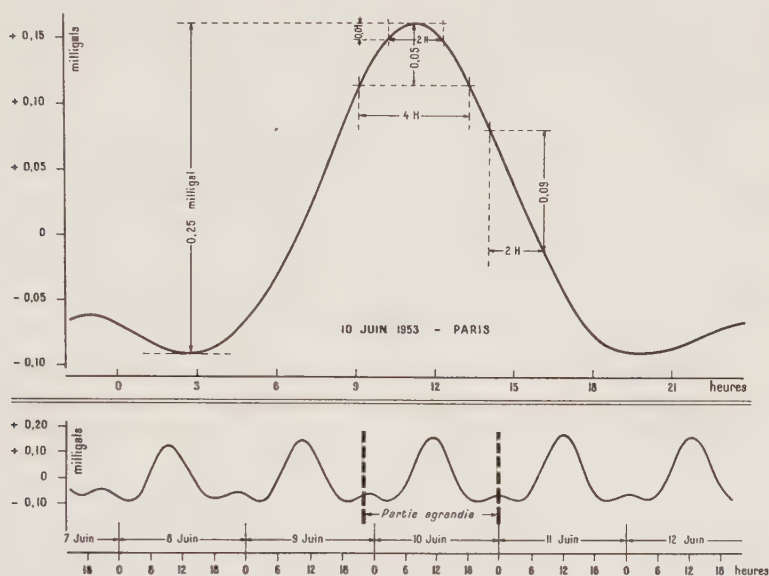


Fig. 3. Influence Luni-Solaire. — Lunisolar influence.

à partir de quelle durée l'influence $L-S$ introduit un écart non négligeable sur les valeurs des stations. On peut assimiler avec une bonne approximation la courbe de la planche 3 à une fonction sinusoïdale de la forme

$$y = a. \cos \omega t + b. \cos 2\omega t$$

dans laquelle les quantités a , b et ω sont des données expérimentales (figure 4) ; il est alors assez facile de calculer la valeur moyenne de la flèche médiane, différence d'ordonnées entre la courbe et sa corde, au milieu de celle-ci ; ce calcul est réalisé pour différentes valeurs de 2Δ , durée du programme de mesures. Les détails de ce calcul sont élémentaires, et nous donnons immédiatement le résultat :

pour une durée de 2 h 30, on trouve 0,006 mgal (max. 0,016)

pour une durée de 5 h, on trouve 0,022 mgal (max. 0,058)

pour une durée de 7 h 30, on trouve 0,049 mgal (max. 0,115)

Ces résultats conduisent au tracé d'une courbe démontrant que la flèche moyenne ne dépasse 0,01 qu'à partir d'une durée de trois heures. Un tel calcul

est évidemment approché, puisqu'il est valable seulement pour une région particulière de la courbe d'influence L - S .

Bien plus significatifs sont les résultats tirés de mesures effectivement réalisées sur le terrain, dont nous allons maintenant donner un exemple.

Notre but est de dégager l'erreur moyenne commise sur les mesures aux stations en fonction de la durée d'un programme, suivant que l'on effectue ou non la correction L - S . Nous avons essayé de nous rapprocher du cas idéal où l'on compare le résultat d'une mesure expérimentale à une valeur vraie en procédant de la manière suivante :

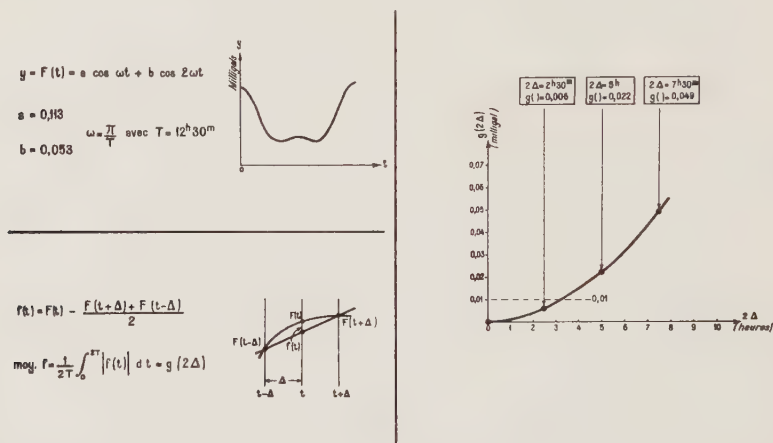


Fig. 4. Calcul approché de la flèche moyenne. — Approximate computation of the mean amplitude.

les mesures à analyser sont constituées par une succession de programmes telle que l'on dispose d'une lecture à la base à peu près toutes les deux heures, augmenter l'intervalle de temps séparant deux bases revient à supprimer une ou plusieurs lectures intermédiaires, et à les considérer maintenant comme des lectures effectuées en des stations ordinaires,

dans le cas présent, la précision des valeurs de g déterminées aux bases est connue; calculée après compensation du réseau par la méthode des moindres carrés, elle a été trouvée égale à 2,1 centièmes de milligal, précision bien supérieure à celle que l'on observe pour les stations ordinaires,

dès lors, il est possible de comparer la valeur d'une base quelconque à celle que l'on obtient en la considérant comme une station ordinaire; de cette façon, on accède à une détermination presque exacte de l'erreur commise.

Le graphique de la figure 5 illustre la façon dont on a procédé; il montre comment a été traitée une succession de lectures effectuées à 2 heures d'intervalle entre quatre bases différentes A, B, C, D ; on a déterminé les erreurs commises sur les valeurs centrales B et C , considérées comme stations ordinaires d'un programme de 6 heures allant de A à D . La partie supérieure présente les

erreurs observées si l'on ne fait pas la correction $L-S$; la partie inférieure montre ce que deviennent ces erreurs lorsque l'on effectue la correction: elles sont en général diminuées.

L'exemple que nous présentons consiste en une statistique portant sur 112 déterminations de ce genre; bien que ce nombre ne soit pas très élevé, on peut

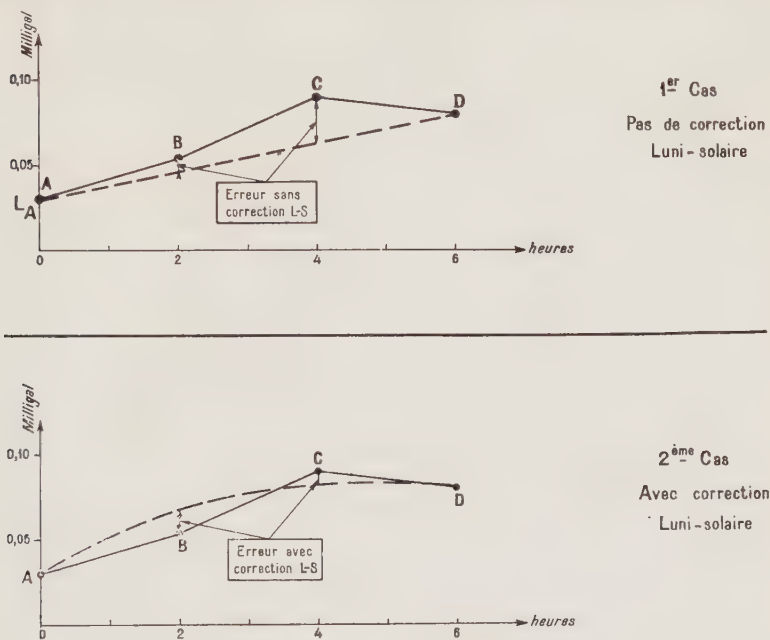
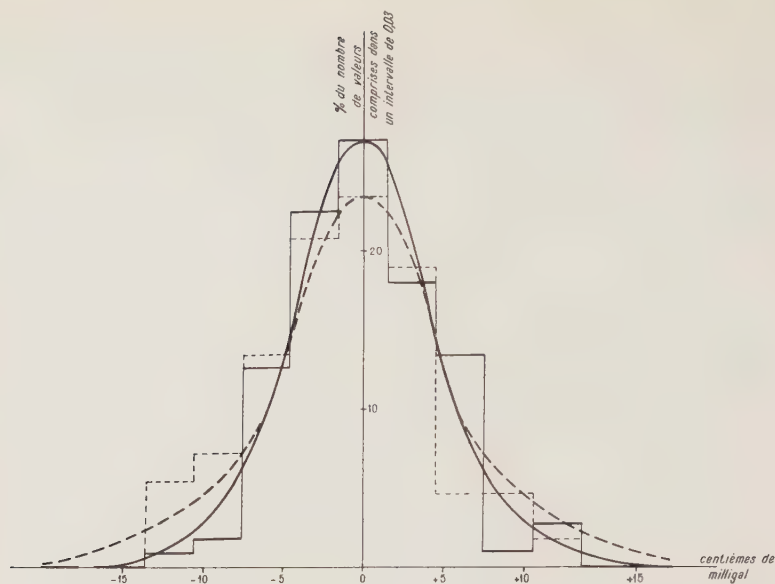


Fig. 5. Principe du calcul d'erreur. — Principle of error calculation.

voir sur la figure 6 que la répartition statistique des écarts individuels est satisfaisante, dans un cas comme dans l'autre. On remarque immédiatement que la courbe en traits interrompus, qui correspond au cas où l'influence $L-S$ n'est pas corrigée, définit une erreur supérieure à celle qui résulte de la courbe en traits pleins. Ce caractère s'accuse bien davantage lorsque l'on fait intervenir la durée moyenne des programmes, ainsi qu'on peut le voir sur la figure 7.

Les valeurs individuelles forment maintenant 5 groupes (concernant de 20 à 24 valeurs) pour lesquels on a calculé la moyenne arithmétique de l'erreur et de la durée; un segment parallèle aux abscisses indique l'intervalle de temps auquel correspond chaque point. La partie supérieure de la figure présente les résultats obtenus sans correction $L-S$. La valeur moyenne de l'erreur est manifestement croissante en fonction de la durée; elle atteint environ 0,06 milligal, soit à peu près le double de l'erreur initiale, pour des programmes d'une durée de 9 heures. Dans le cas où l'on effectue la correction $L-S$, il n'est pas possible de dégager une loi; seul le point correspondant aux programmes les plus longs



- Répartition des écarts observés sans correction L-S. — Distribution of deviations observed without lunisolar correction.
 — Répartition des écarts observés avec correction L-S. — Distribution of deviations observed with lunisolar correction.

Fig. 6. Groupement statistique des écarts observés. — Statistical distribution of observed deviations.

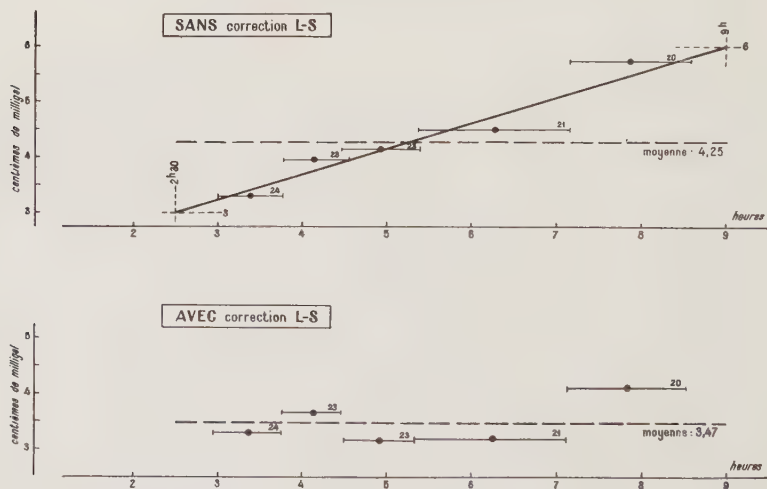


Fig. 7. Mission France, erreur moyenne en fonction de la durée. — Survey France, mean error as a function of time.

se place à environ $\frac{1}{2}$ centième au-dessus de la droite définissant la valeur moyenne de l'erreur commise dans ce cas. On remarquera que l'erreur caractérisant les programmes les plus courts, de durée moyenne 3 h 20, est la même dans les deux cas, ce qui confirme les remarques faites précédemment sur l'inutilité de la correction tant que la durée du programme ne dépasse pas nettement deux heures.

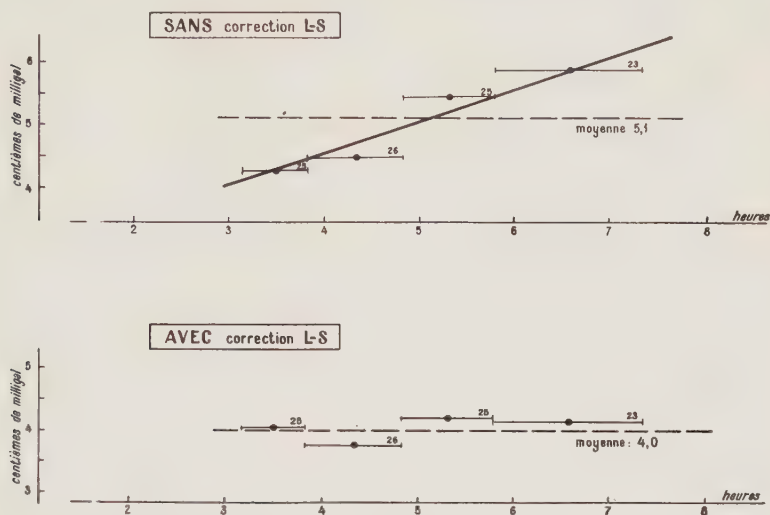


Fig. 8. Mission Sénégal, erreur moyenne en fonction de la durée. —
Survey Sénégal, mean error as a function of time.

La figure 8 présente une série de résultats analogues tirés d'une autre mission; les erreurs sont un peu plus élevées que dans le cas précédent, car il s'agit d'une étude coloniale dont le réseau de bases est moins précis, mais la loi est bien la même.

Nous pouvons donc maintenant *mesurer* le gain de précision que permet de réaliser l'introduction de la correction $L-S$; ce sera un nombre ε tel que

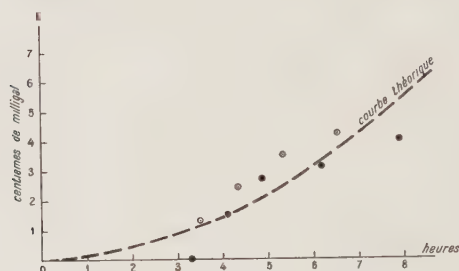
$$E^2 = e^2 + \varepsilon^2$$

E et e caractérisant respectivement les erreurs moyennes commises sans ou avec correction $L-S$.

La figure 9 donne les valeurs trouvées pour ε dans les deux exemples présentées, en fonction de la durée moyenne des programmes; les points expérimentaux se placent bien au voisinage de la courbe calculée de la façon indiquée précédemment; on remarquera que les points représentatifs de la mission coloniale se placent au-dessus de la courbe théorique: l'influence luni-solaire était en effet plus forte dans ce cas qu'à Paris.

FRANCE			
Durée	E	e	δ
3 h 23	3,30	3,30	0
4 h 09	3,95	3,65	1,5
4 h 56	4,12	3,15	2,7
6 h 15	4,45	3,20	3,1
7 h 50	5,70	4,08	4,0

SÉNÉGAL			
Durée	E	e	δ
3 h 30	4,25	4,05	1,3
4 h 20	4,48	3,77	2,4
5 h 19	5,45	4,20	3,5
6 h 35	5,87	4,13	4,2

Variations de l'erreur ε en fonction du temps

- Mission France. — Survey France.
 ○ Mission Sénégal. — Survey Sénégal.

Fig. 9. Erreur ε introduite par l'influence $L-S$ non corrigée. —
 Error ε introduced by uncorrected lunisolar influence.

ASSOUPLISSEMENT APPORTÉ AU MODE OPÉRATOIRE

Les études qui précèdent, ainsi que d'autres analogues, prouvent surabondamment que si l'on effectue la correction $L-S$, la durée des programmes peut être portée à 6 ou 7 heures, ce qui amènerait pratiquement à ne passer aux bases que trois fois dans la journée. Ces études prouvent également que si la durée est maintenue inférieure à 3 heures, il est tout à fait superflu d'appliquer cette correction à chaque station.

Il ne paraît pas inutile d'insister un peu sur l'avantage pratique que représente cette possibilité d'allonger les programmes. Soit à réaliser les mesures en des points répartis comme nous l'avons représenté figure 10; il s'agit d'une étude constituée par des profils rectilignes alignés $N-S$, la circulation dans le sens $E-W$ n'étant possible que de loin en loin. Supposons que la durée d'un parcours $N-S$, temps de mesures compris, soit de l'ordre de deux heures. En procédant par programmes courts, les bases seront réparties comme il est indiqué sur la partie gauche de la figure, et les mesures seront effectuées avec retours aux bases à chaque extrémité de profil. En procédant par programmes de 6 heures environ, il est visible que l'on pourra mesurer toutes les stations en utilisant seulement les deux bases A et D , B et C devenant inutiles. De plus, un excellent contrôle sera fourni par la reprise automatique des stations $abcd$, situées dans un cas vers la partie centrale d'un programme et dans l'autre au

voisinage immédiat d'une mesure de base. On voit que la distance à parcourir est fortement diminuée dans le cas des programmes longs, d'autant plus que l'on part d'une base A pour se retrouver au même endroit après deux programmes, ce qui n'est pas réalisé dans le premier cas ; le rendement est donc amélioré en raison de la réduction sensible des temps morts.

Cet exemple apporte un nouvel argument en faveur de l'utilisation de la correction $L-S$; permettant la réalisation de programmes longs, elle conduit à diminuer le nombre des bases (il est ici divisé par 2) et, partant, à réduire le

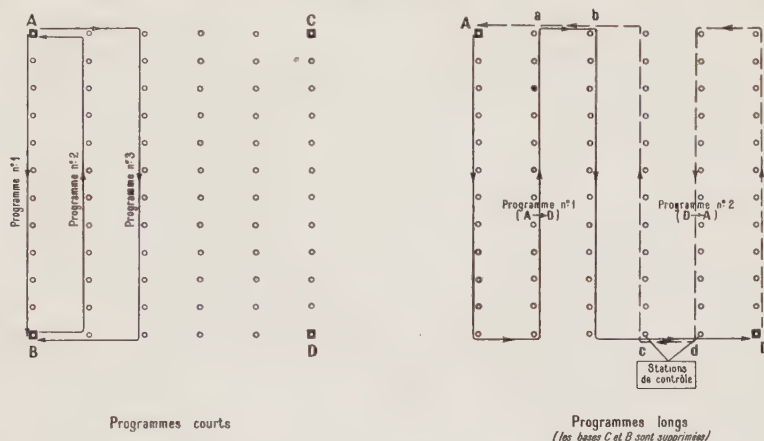


Fig. 10. Intérêt présenté par les programmes longs. — Advantage of long-term programmes.

temps consacré à l'exécution d'un réseau d'enchaînements ; de plus, on aura certainement amélioré la qualité d'ensemble des résultats en diminuant l'effet de la propagation en chaîne des écarts de fermeture.

On doit cependant noter que le travail dans ces conditions imposera un certain nombre de précautions :

il faudra avant tout bien connaître les conditions de fonctionnement du gravimètre utilisé,

il sera absolument nécessaire de multiplier les mesures de contrôle judicieusement choisies,

enfin, la critique des dérives observées devra être très serrée.

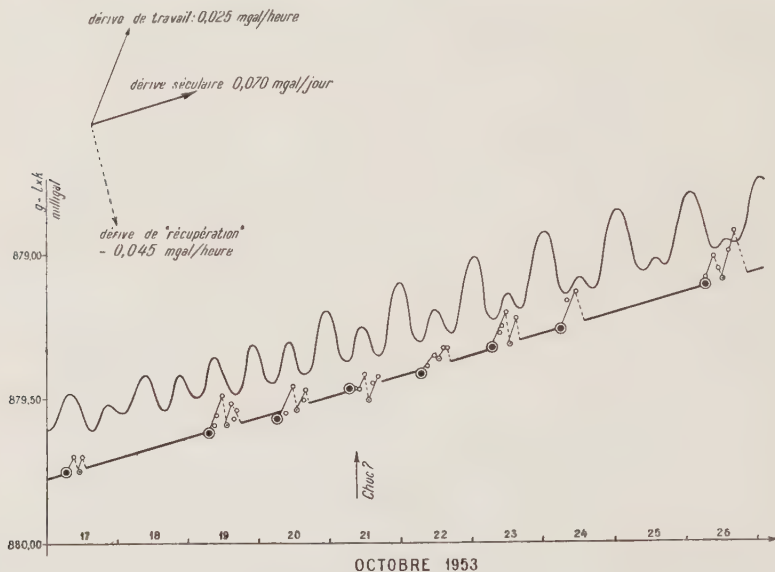
Une fois de plus, la correction de l'influence $L-S$ va nous rendre un précieux service en nous permettant de préciser ces différents points.

ÉTUDE DU COMPORTEMENT DES GRAVIMÈTRES

Les utilisateurs du gravimètre North-American ou d'autres analogues considèrent avec juste raison que les conditions de fonctionnement d'un tel appareil demeurent sur beaucoup de points assez mystérieuses. On a observé par exemple que les dérives ne sont pas les mêmes lorsque l'appareil travaille ou lorsqu'il est

au repos, mais la différence n'est pas facile à mesurer; la détermination des dérives moyennes est restée très longtemps incertaine, car l'influence $L-S$ introduisait des variations d'amplitudes plus grandes que celles que l'on cherchait à mettre en évidence.

Depuis que l'on sait corriger cette influence, les choses se sont singulièrement éclaircies. La figure 11 présente un bel exemple d'étude sur le comportement d'un gravimètre, réalisée à partir de mesures aux bases corrigées de l'effet $L-S$: les gros points encerclés sont relatifs aux mesures faites chaque matin, après



- ⊙ Première mesure de la journée. — First measurement of the day.
- ⊙ Reprise du travail l'après-midi. — Resumption of operations in the afternoon.
- Mesure en cours de travail. — Measurement during operations.

Fig. 11. Etude des dérives. — Study of drifts.

la longue période de repos de la nuit; ces points s'alignent bien sur une droite dont la pente caractérise la *dérive séculaire* du gravimètre, les petits points encerclés représentent la mesure faite au début de l'après-midi, après la courte interruption d'une heure environ consacrée au repas; on remarque qu'à l'exception d'un seul, ces points se placent également sur la droite de dérive séculaire,

enfin, les petits cercles concernent les mesures faites aux bases pendant le travail; on voit immédiatement qu'ils s'écartent nettement de la droite représentative de la dérive séculaire, et qu'ils définissent des segments sensiblement parallèles dont la pente caractérise la *dérive de travail*.

Une autre dérive peut être relevée sur ce graphique, à partir des segments

tracés en pointillé: cette dérive, dite de „récupération”, caractérise la reprise par l'appareil de son équilibre, lorsqu'il passe de l'état de travail à l'état de repos.

Nous avons matérialisé par trois vecteurs les pentes moyennes correspondant à ces trois sortes de dérive; on remarquera que la pente la plus élevée en valeur absolue est celle du vecteur „récupération”.

On notera également que les points de la journée du 21 se placent tous, à l'exception d'un seul, un peu trop bas, l'écart étant de l'ordre de 0,05 milligal; il s'agit vraisemblablement d'un petit choc dont l'effet n'a été récupéré qu'au cours de la nuit suivante.

L'analyse de ces phénomènes en fonction de la constitution de l'appareil nous entraînerait loin de notre sujet; au demeurant, il nous suffit d'en connaître l'existence et, si possible, la mesure moyenne.

Nous avons fait figurer sur la figure 11 la courbe de l'influence $L-S$ (augmentée de la dérive séculaire). On voit que, non corrigée, cette influence aurait complètement masqué le phénomène étudié.

La conséquence pratique de cette étude, et d'autres analogues, est d'imposer aux opérateurs des consignes très strictes en ce qui concerne *le rythme du travail*; tout arrêt prolongé au cours d'un programme se traduira par une variation importante dans la pente de la dérive; sa répartition linéaire n'aura de sens que si l'on peut annuler l'effet d'un tel arrêt, en effectuant une mesure à la même station immédiatement avant et après l'interruption.

Par ailleurs, la connaissance de la dérive moyenne de travail permet de juger si telle ou telle dérive observée est acceptable, en considérant non plus sa valeur même, mais sa différence avec la valeur moyenne théorique. Dans l'exemple présenté, pour lequel la dérive de travail a été trouvée égale à $+ 0,025$ par heure, une dérive totale de $+ 0,12$ en 4 heures devra être considérée comme tout à fait normale (écart de $+ 0,02$ par rapport à la dérive de travail moyenne); au contraire, une dérive de $- 0,05$, observée dans les mêmes conditions, quoique moins suspecte a priori, ne devra pas être acceptée sans contrôle (écart de $- 0,15$ par rapport à la valeur théorique).

CONCLUSION

Des études analogues à celles que nous venons de présenter peuvent être facilement réalisées sur le terrain; elles doivent normalement conduire à une amélioration du rendement et surtout de la qualité des résultats. En effet, grâce à la correction $L-S$, la critique des mesures a gagné en efficacité.

Nous terminerons par un exemple emprunté à une mission récente, qui montre qu'une étude soignée des mesures peut conduire à détecter des écarts que l'on pourrait facilement confondre avec les erreurs instrumentales. Nous avons vu que la précision des mesures de g était en général de l'ordre de 3 à 4 centièmes de milligal; dans ces conditions, il est certain qu'une erreur de plusieurs dixièmes sera beaucoup plus facile à mettre en évidence qu'une erreur inférieure à 0,10 milligal.

La figure 12 montre de quelle façon on peut procéder pour découvrir et éliminer de telles erreurs : un programme de 20 stations, réalisé avec une durée de moins de 2 heures, accusait une dérive de $-0,07$, alors que la dérive moyenne théorique devait être de $+0,06$; on se trouvait en présence d'un écart de $-0,13$ qui, sans être très considérable, n'en était pas moins suspect. On décida de recommencer deux stations centrales, ce qui fut fait quelques jours après au cours d'un programme présentant cette fois une dérive normale. Les nouvelles valeurs trouvées pour ces deux stations furent utilisées comme bases pour le dépouillement primitif, ce qui permit de fractionner la dérive totale de

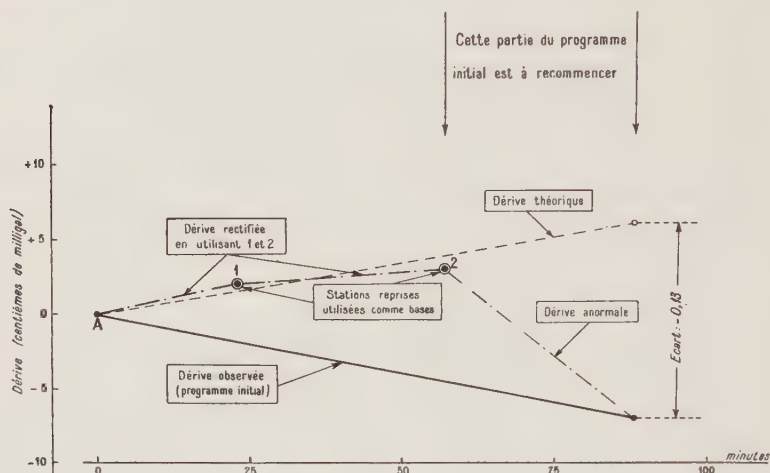


Fig. 12. Exemple d'utilisation des données sur la dérive. — Example of utilisation of data regarding drift.

-7 en trois parties : $+2$ (23 minutes), $+1$ (34 minutes) et -10 (31 minutes). On avait ainsi localisé dans le dernier tronçon un incident dans le fonctionnement du gravimètre, et toutes les dernières stations furent reprises, donnant par rapport aux valeurs primitives des écarts compris entre 6 et 11 centièmes de milligal ; une nouvelle reprise ultérieure de deux de ces stations confirma un peu plus tard la seconde série de valeurs. Sans une connaissance précise de la marche de l'instrument (dérive de travail), il aurait été impossible de détecter ces erreurs, et pourtant on avait affaire à un programme court (1 h 30).

Dans une étude à forte densité de stations, on doit mettre tout en œuvre pour éviter de tels écarts, car la gravimétrie de détail n'a d'intérêt que si les résultats sont très précis.

La mise en œuvre de programmes de longue durée n'est donc concevable que si elle s'accompagne d'une critique très serrée des mesures faites, appuyée sur une étude soignée du comportement instrumental.

Nous pouvons donc conclure qu'en nous permettant de mieux comprendre certains phénomènes et en facilitant dans une certaine mesure notre tâche sur

le terrain, la correction luni-solaire constitue désormais un outil indispensable en prospection gravimétrique.

DISCUSSIONS

Mr. J. GOGUEL: L'analyse très fine que présente M. Neumann nous permet de pénétrer plus avant dans la compréhension des phénomènes, et doit conduire à un meilleur contrôle des liaisons entre bases.

Mr. W. DOMZALSKI: The irregularities of the results can be caused by various things, such as sudden jumps, or failure in thermostatic control, or a leak in thermos, enclosing the system.

Mr. R. NEUMANN: Cet exemple est relatif à une période où la dérive instrumentale a été particulièrement régulière, et les mesures n'ont subi aucune rectification. Il est assez rare en effet de disposer d'une période aussi longue au cours de laquelle on ne relève aucun incident de marche.

Mr. W. DOMZALSKI: The Worden gravimeter has normally a regular drift.

Mr. C. MORELLI: Each gravimeter is somewhat individual. The Worden gravimeter has a regular drift, and it jumps very seldom: North American, Frost and others seem to have more irregular drifts, because they more often jump. The Western gravimeter jumps too, but it has only a rather small drift.

E.A.E.G. ABSTRACT SERVICE

EXPLORATION — GENERAL

148. *The Floor of the Atlantic Ocean.*

Nature, Vol. 171, No. 4359, pp. 857-860, May 16, 1953.

A discussion at the Royal Society, concerning sedimentation, and the deeper structure below the layers which can be sampled. The more important points discussed were: sediment thickness; turbidity currents; determination of climatic changes in the past from sedimentary study; results of gravity surveys; pebbles found in cores from the east Atlantic; ocean bed movements compared with continent movements; seismic refraction work; coring; distribution of epicentres of recent earthquakes; the problem of guyots; and the significance of measurements of head flow under the oceans.

149. *Safety is Important to Geophysics.*

B. W. Sorge, a paper read at the Pacific Coast Meeting of the S.E.G., at Los Angeles, California, Oct. 31, 1952. (Not yet published).

Geophysicists hold almost all responsible positions in geophysical exploration. As a result, they are responsible for the safety of workers under their direction. The Committee on Safety of the S.E.G. has made a study of reports to the Geophysical Accident Information Exchange. Much information has been accumulated that formerly was not available and which will be of benefit to geophysical operators. Evidence shows that well-coordinated safety efforts are worthwhile and that cooperative efforts within the industry in the cause of safety and accident prevention have been successful.

150. *Analog Computer Solves Geophysical Problems.*

S. Kaufman, Electronics, Vol. 26, No. 6, pp. 175-177, June, 1953.

The need for rapid computation of geophysical data arises from the large number of calculations required. The analog computer described was devised to perform rapidly the arithmetic operations required to interpret potential-field data.

151. *Intensity of Oil Search.*

B. O. Lisle, Oil Forum, Vol. 7, No. 7, pp. 233-235, July, 1953.

Exploration rights over 700,000 sq. ml. in 21 countries in western Asia and north-eastern Africa are held by various oil companies. The current activities in each country concerned are described.

152. *Geophysics — Annual Review 1952.*

R. H. Joesting, Mining Engineering, Vol. 5, No. 2, pp. 151-155, 1953.

The outstanding discoveries, advances and trends in geophysics during 1952, with emphasis on mining and engineering geophysics, are outlined. Information was obtained from about 75 correspondents in all parts of the world except the U.S.S.R. satellite countries.

153. *Contribution of Geophysics to Geologic Exploration* (In German).

H. Reich, Deutsche Geol. Gesell. Zeitschr., Band 100, pp. 198-203, 1950.

A review of the application of geophysical methods to geologic investigations and in prospecting for minerals.

154. *Geophysical Measurements of the Depth of the Weathered Rock Mantle*, in *Symposium on Surface and Subsurface Reconnaissance*.
D. Wantland, Amer. Soc. for Testing Materials, Special Tech. Pub. 122, pp. 115-135, 1952.

Geophysical field studies are described which were made to ascertain the depth of weathered overburden mantle rock at the proposed site of a dam, on the American River in California. The applications of the electrical resistivity, the seismic refraction, and the magnetic methods in attacking this problem are discussed. The interpretation procedures employed are explained. Examples of results are presented which show that the geophysical and core drill determination of the depth to sound rock agreed with less than 4 ft. It is brought out that geophysics is a useful tool for exploration at sites where the amount of rock that would have to be stripped is a factor.

155. *Experience with Geophysics in New York State*, in *Symposium on Surface and Subsurface Reconnaissance*.
P. H. Bird, Amer. Soc. for Testing Materials, Special Tech. Pub. 122, pp. 151-155, 1952.

A discussion on the use of seismic and electrical resistivity methods by the New York State Bureau of Soil Mechanics. The applications and limitations of each method are discussed. On the whole, the New York Bureau has emphasized use of the seismic method.

156. *Sedimentary Volumes in Gulf Coastal Plain of United States and Mexico*, Pt. 6, *Geophysical Aspects*: Geol. Soc. Amer. Bull., Vol. 63, No. 12, Pt. 1, pp. 1221-1228, 1952.

A study of the distribution, thickness, volume, and general character of Mesozoic and Cenozoic sedimentary rocks of the Gulf Coastal Plain province rimming the western and northern shores of the Gulf of Mexico. On the basis of all geophysical data in an area which has probably been geophysically explored more intensively than any comparable large area in the world it is concluded that: the regional dip toward the Gulf of Mexico extends to the coast line without any indications of a synclinal axis at or immediately beyond the coast; that the thickness of sediments at the coast line is about 40,000 feet; and that Pre-salt sediments are thin, absent, or metamorphosed.

157. *Advances in Geophysics*, Vol. 1.

H. E. Landsberg, Book Published by Academic Press, Inc., New York, 1952.

This book is a collection of eight monographs on various phases of geophysics, as follows:

- "Automatic Processing of Geophysical Data."
- "Some New Statistical Techniques in Geophysics."
- "Studies of the General Circulation of the Atmosphere."
- "Exploration of the Upper Atmosphere by Meteoritic Techniques."
- "Unsolved problems in Physics of the High Atmosphere."
- "Esturaine Hydrography."
- "The Earth's Gravitational Field and Its Exploitation."
- "Aeromagnetic Surveying."

158. *European Association of Exploration Geophysicists. Paris Meeting.*

Dr. T. C. Richards, *Nature*, Vol. 172, No. 4370, pp. 189-191, Aug. 1, 1953.

At the fourth meeting of the E.A.E.G., held in Paris during May 20-22, twenty-two papers were read.

K. H. Seelis (Germany) gave examples of seismic observations over faulted areas.

H. A. Rühmkorf (Germany) gave added examples of seismic travel times in faulted areas.

H. Dürbaum (Germany) presented formulae for the direct determination of varying layer velocities from the records.

W. Elberkirch (Germany) described reflection work in the Swabian Molasse basin of Bavaria.

H. Menzel (Germany) described laboratory studies of the propagation of seismic waves in a solid body with elastic afterworking.

J. Dienesch & H. Richard (France) presented geometric constructions that simplify the conversion of reflection time sections when the velocity is varying.

S. H. Davidson, R. Westwater & J. Hancock (Gt. Britain) talked about explosives in seismic prospecting.

G. M. Habberjam and J. T. Whetton (Gt. Britain) described resistivity investigations of a washout feature in coal measure strata.

E. J. Polak (Gt. Britain) described application of resistivity methods in establishing the base of water-bearing rocks in the Cannock Chase coalfield.

J. J. Breusse and G. Huot (France) showed how electrical and seismic refraction methods were used to find water in the desert areas of Mauritania (Morocco).

A. P. Poirault (France) reviewed the development of gamma-ray logging, micro-logging, and side-wall sampling in boreholes for minerals other than oil.

I. Wendt (Germany) described a method of measuring the radioactive potassium in thin deposits, using two counting tubes.

L. Solaini (Italy) described an instrument for measuring resistivity with alternating current at 20 c/sec.

S. Matweber and K. Jung (Germany) gave an account of magnetic measurements in the Red Iron District of Lahn and Dill, with particular regard to the difficult local geology.

F. Sumi (Yugoslavia) discussed the quantitative interpretation of magnetic measurements.

A. Lundbak (Denmark) reviewed the limiting factors in aeromagnetic surveys.

J. M. Bruckshaw (Gt. Britain) discussed the initial adjustments of vertical force variometers.

C. Aynard (France) presented an interpretation of gravity results obtained in the Gharb basin of Morocco.

C. Morelli (Italy) discussed the diurnal variation of gravity in Europe.

A. M. Selem and C. Monnet (Italy) gave an account of seismic reflection, telluric, and gravity surveys in the Ferrara basin of northern Italy.

M. Matschinski (France) discussed the degree of certainty in geophysical interpretation.

H. Richard (France) talked about safety regulations in geophysical prospecting.

159. *Instrumentation for Geophysical Exploration.*

D. H. Clewell, R. A. Broding, G. B. Loper, S. N. Heaps, R. F. Simon, R. L. Mills, & M. B. Dobrin, *Rev. Sci. Instr.*, Vol. 24, No. 4, pp. 243-266, April, 1953.

A review of instruments used in prospecting by the seismic, gravity, electrical radioactive and magnetic methods.

160. *A Cooperative Plan in Student Education.*

C. H. Green, *Geophysics*, Vol. 18, No. 3, pp. 525-531, July, 1953.

Effective exploration is a combination of well designed equipment and competent personnel. The latter factor attains special importance as exploration problems become more complex and competition increases with other industries for scientific manpower. A cooperative plan for undergraduate university students is described wherein

aptitudes are measured in a guided course of actual exposure to various phases of petroleum exploration.

161. *A Safety Programme — Management's Responsibility.*

G. H. Westby, *Geophysics*, Vol. 18, No. 3, pp. 532-538, July, 1953.

The extremely poor safety record of the contract geophysical industry should be corrected not only for the humanitarian and economic gains it would bring the individual company, but also for the improvement it would make in the industry's public relations and ability to attract technically trained men. Management of the geophysical contracting companies should be cognizant of the importance of such a programme and eager to participate in the S.E.G. safety programme. Management of the oil companies, represented by those who are responsible for hiring contract geophysical companies, should help assure the success of this programme and its related good consequences to the oil industry by demanding that geophysical contracting companies, in addition to meeting all their other requirements, have a safety programme and cooperate with the S.E.G. in its safety programme.

162. *Application of Vertical Gradients and Comparison of Different Geophysical Methods in a Difficult Area.*

A. M. Selem & C. Monnet, *Geophysical Prospecting*, Vol. 1, No. 3, pp. 208-219, Sept., 1953.

Seismic reflection, telluric, and gravity results are given for the uplifted area of Ferrara, in Northern Italy. Agreement is shown between the available shallow seismic data and gravity evidence. For a portion of the above area where seismic results are particularly poor the vertical gradients method gives a resolution of a gravity anomaly and confirms the telluric information. The residual gravity values, the vertical gradients and the telluric data along a seismic line crossing the zone are compared with seismic results and with evidence from adjacent wells.

SEISMIC — GENERAL

163. *Applications of Seismic Methods to Foundation Exploration, in Symposium on Surface and Subsurface Reconnaissance.*

A. M. Johnson and R. H. Wesley, *Amer. Soc. for Testing Materials*, Special Tech. Pub. 122, pp. 142-150, 1952.

This paper discusses the development of the seismic refraction method, describes the methods of field operation and interpretation of results, and relates its use to several foundation or subsurface exploration problems. Several applications are described; in all instances it was found that the geophysical technique supplied the required information about subsurface conditions in a comparatively short period of time and with accuracy.

164. *Results of Seismic Investigations in the Peissenberg Coal Mine* (In German).

H. Reich, *Erdöl u. Kohle*, Jahrg. 4, Heft 9, pp. 538-542, 1951.

Velocities of propagation of seismic waves were determined at a depth of 650 m below ground, using electric microphones and mechanical seismographs. The velocity of longitudinal waves in variegated Molasse was found to be 3,200 m/sec., in adjoining sandstone formations 3,500 m/sec. The velocities of transverse waves were found to be 1,800 and 2,150 m/sec. respectively. Clearly observable phenomena of refraction of seismic waves were observed along an inclined folded formation of rock having high seismic velocity, about 4,600-5,200 m/sec.

165. *Seismic Prospecting at Toyosuto Coalfield, Hokkaido* (In Japanese with English Summary).

T. Tateishi, Geol. Survey Japan Bull., Vol. 2, No. 9, pp. 29-34, 1951.

Refraction surveying indicated presence of layers with velocities of 1.5, 1.8, 2.1, 2.4, 2.8, and 3.5 km/sec. Geologic data suggest these are the Quaternary (1.5), Taki-kawa (1.8-2.1), and Ishikari (2.4-3.5) formations.

166. *Offshore Seismic Exploration in Ube Coal Field* (In Japanese with English Summary).

K. Iida and S. Kurihara, Geol. Survey Japan, Report No. 146, p. 61, 1952.

Offshore refraction surveys of the coal field were made between 1947 and 1950. Sled-mounted detectors dragged across the fairly flat sea bottom proved more efficient than detectors suspended from floats, which though handled very rapidly were disturbed by water motion. Thicknesses of Quaternary sediments, Tertiary sediments, and basement rock were mapped to depths of 300 m.

167. *Exploration.*

Oil & Gas J., Vol. 52, No. 3, p. 137, May 25, 1953.

Brief descriptions of seismic equipment on display at the Petroleum Exposition, Tulsa, including the latest design of seismic vehicles, a portable outfit and a shot hole drill operating with compressed air.

168. *Seismic Refraction Measurements in the Atlantic Ocean, Part 3.*

I. Tolstoy, R. S. Edwards, & M. Ewing, Seismol. Soc. Amer. Bull., Vol. 43, No. 1, pp. 35-48, 1953.

Four fully or partly reversed seismic refraction measurements were made during the Winter of 1950 in the North Atlantic Basin by the whaleboat method. The results are discussed.

169. *Seismic Refraction Profile across the Gulf of Maine.*

S. Katz, R. S. Edwards & F. Press, Geol. Soc. Amer. Bull., Vol. 64, No. 2, pp. 249-252, 1953.

One partially reversed refraction profile across the Gulf of Maine has been interpreted as indicating a surface layer 5.1 km deep east of Falmouth, in which the compressional wave velocity is 5.3 km/sec. thinning to the east over a distance of about 50 km. The underlying material has a velocity of about 6.25 km/sec.

170. *Measurements of Ice Thickness in Dronning Maud Land, Antarctica.*

G. de Q. Robin, Nature, Vol. 171, No. 4341, pp. 55-58, 1953.

Using standard seismic reflection techniques, a profile across the ice cap was determined. In order, the following features were observed: floating ice shelves, coastal ice hills, mountain ice sheet, and mountain inland plateau. The velocities of ice were: longitudinal, 3,800 m/sec; shear, 1,650 m/sec; and Rayleigh. 1,050 m/sec.

171. *The Seismic History of Southwestern New Mexico.*

A. I. Innes, Geophysics, Vol. 18, No. 1, pp. 142-159, 1953.

The seismic history of southwestern New Mexico is outlined, indicating which fields were found by refraction or reflection methods.

172. *Seismic Refraction Observations North of the Brownson Deep.*

J. B. Hersey, C. B. Officer, H. R. Johnson, & S. Bergstrom, Seismol. Soc. Amer. Bull., Vol. 42, No. 4, pp. 291-306, 1952.

Results of several refraction profiles made on the rise to the north of the Brownson Deep are presented.

173. *Seismic Refraction Shooting in an Area of the Eastern Atlantic.*

M. N. Hill, Roy. Soc. London Phil. Trans., Ser. A, Vol. 244, No. 890, pp. 561-596, 1952.

A new method of seismic refraction shooting in which hydrophones suspended at a depth of about 100 feet below the surface of the sea act as receivers for compressional waves developed by depth charges exploding at a depth of approximately 900 feet.

SEISMIC — INSTRUMENTAL

174. *Patents.* Abstracts in Geophysics, Vol. 18, No. 3, p. 703, July, 1953.

U.S. 2,625,129. 13 Jan. 1953. A float for a detector cable used in marine seismic operations.

U.S. 2,626,004. 20 Jan. 1953. A circuit for firing a seismograph shot in coincidence with a distinctive timing line.

U.S. 2,626,381. 20 Jan. 1953. A variable-impedance cable-like seismometer,

175. *Theory of the Combination Seismograph* (In German).

M. Weber, Z. angew. Math. Phys., Vol. 4, No. 1, pp. 57-81, 1953.

This instrument consists of several seismographs arranged in series or in other combinations, each element having its own (electronic) amplification system. The essential features and mode of operation are outlined, followed by a general theoretical treatment which indicates the conditions necessary to obtain a precise instrument. Four instruments are depicted and a description is given of the 2-stage electronic amplifiers used in conjunction with them.

176. *How Magnetic Recording aids Seismic Operations.*

E. J. Handley, Oil & Gas J., Vol. 52, No. 37, pp. 158-9, Jan. 11, 1954.

Seismic recordings on magnetic tape may be played back and, under controlled conditions, the operator can obtain optimum settings for many of the variables. These variables only apply to instrument adjustments. Other adjustments, due to field technique, must be carried out at the time the record is made.

The main advantage is the improvement in record quality that may be obtained. When playing the record back, traces can be mixed and a separate record of the result obtained. Employing a second recorder, similar traces of different records can also be mixed.

177. *Patents.* Abstracts in Geophysics, Vol. 18, No. 4, p. 953, October, 1953.

U.S. 2,634,398. 7 April, 1953. A mixing system which eliminates an undesired component of seismic waves.

U.S. 2,635,705. 21 April, 1953. Method and apparatus using seismic waves to modulate a sonic or supersonic carrier wave.

U.S. 2,636,160. 21 April, 1953. A moving-coil permanent-magnet electro-magnetic type geophone for low frequencies.

U.S. 2,637,839. 5 May, 1953. A reluctance-type rotational geophone.

U.S. 2,638,402. 12 May, 1953. Apparatus for scanning seismic records.

U.S. 2,638,578. 12 May, 1953. A capacitive seismometer.

U.S. 2,640,186. 26 May, 1953. A shot-moment recording system.

U.S. 2,640,187. 26 May, 1953. A shot-moment recording system.

U.S. 2,641,749. 9 June, 1953. A time-break recording system.

U.S. 2,643,367. 23 June, 1953. A magnetostriction seismometer.

U.S. 2,643,869. 30 June, 1953. A variable air-gap seismometer.

178. *Seismic Recording on Magnetic Tape.*

G. B. Loper & R. R. Pittman, Geophysics, Vol. 19, No. 1, pp. 104-115, Jan. 1954.

A system of recording and reproducing exploration seismograms on magnetic tape is described. Geophones and amplifiers with broad-band response, approximately 4-300 c.p.s., are used to channel the seismic signals to a 13-track tape recorder. The magnetic tape is one inch wide. One of the tracks is used to record a time reference signal. Each broad-band recording is formed into an endless loop and played back in repeating fashion. The signals are fed through a flexible system of filtering and mixing, then examined on the screen of a 12-trace cathode-ray oscilloscope. The sweep of the oscilloscope is synchronized with the loop and, by varying the sweep speed, the entire record, or an expanded portion thereof, is held stationary on the screen. Conventional paper records of the modified record as reproduced on the screen are finally made with a regular seismic camera. Played-back records with variations of filtering and mixing are shown in order to illustrate the potential usefulness of the technique.

(Author's Abstract).

179. *Patents.* Abstracts in Geophysics, Vol. 19, No. 1, p. 157, January, 1954.
U.S. 2,648,055. 4 Aug., 1953. Instrument functioning as seismometer or gravimeter.
U.S. 2,648,979. 18 Aug., 1953. A transducer testing apparatus.
U.S. 2,649,579. 18 Aug., 1953. A capacity-type seismometer.
U.S. 2,651,769. 8 Sept., 1953. A moving coil-seismometer.
U.S. 2,653,302. 22 Sept., 1953. A variable air-gap reluctance type accelerometer.
U.S. 2,653,305. 22 Sept., 1953. Method of checking polarity of seismometers.
U.S. 2,653,306. 22 Sept., 1953. A condenser type seismometer.
U.S. 2,654,077. 29 Sept., 1953. A geophone cable connector system.

SEISMIC — FIELD TECHNIQUE

180. *Patents.* Abstracts in Geophysics, Vol. 18, No. 3, p. 703, July 1953.
U.S. 2,630,188. 3 March, 1953. Shooting method in which an array of shots are fired at different depths or with various time delays.
U.S. 2,632,150. 17 March, 1953. Seismograph spread for marine surveys.
181. *Patents.* Abstracts in Geophysics, Vol. 18, No. 4, p. 953, October, 1953.
U.S. 2,638,176. 12 May, 1953. A method of seismic prospecting in water-covered areas with a towed seismometer spread.
U.S. 2,642,146. 16 June, 1953. A shot hole array for eliminating horizontally travelling waves.
182. *Patents.* Abstracts in Geophysics, Vol. 19, No. 1, p. 157, January, 1954.
U.S. 2,652,550. 15 Sept., 1953. A marine seismometer spread where the seismometers may be maintained at a desired depth.

SEISMIC — INTERPRETATION

183. *Possibilities of Constructing True Ray Paths in Reflection Seismic Interpretation.* H. Dürbaum, Geophysical Prospecting, Vol. 1, No. 2, pp. 125-139, June 1953.
Investigations by a reflection survey on the salt structure of Heide raised the following questions:

- 1) How can the different directions of trend of a series of layers be established?
- 2) How are the contour maps of reflecting horizons to be constructed if there is no general trend of the layers?

To answer these questions, the case of the subsoil consisting of a series of layers with plane reflecting beds and constant layer-velocities is treated strictly. The strike lines of the reflecting planes may be at any angle whatever. However, formulae for constructing contour maps of the reflecting planes have been derived. With these formulae, the problem quoted under 1) has also been solved.

The construction of contour maps is given. For special cases, formulae are obtained which have already been proved by others.

184. *Calculating Reflecting-Horizon Dip, (using Punched-Card Equipment).*

P. Knaplund, P. Fullerton & E. Ford, *Oil & Gas J.*, Vol. 52, No. 9, pp. 71-73, July 6, 1953.

A sample calculation shows how a numerical solution may replace a graphical one. Dip computations are handled in a single step in the automatic processing of seismic data by punched cards.

185. *Master Charts of Theoretical Travel Times for some Stratified Media* (In Russian). V. A. Bugaylo, Akad. Nauk SSSR, Ural-skiy filial, Trudy Gorno-Geol. Inst., Vypusk 19, Geofiz Sbornik 1, pp. 26-32, 1950.

Using logarithmic master charts to determine travel times of direct, refracted, and reflected waves, it is not necessary to assume constant velocity in individual layers. Several cases of the variation of seismic velocity are discussed: velocity linearly increasing with depth; velocity an exponential function of depth; velocity a linear function of the distance from the observation point to shot point. Travel-time curves can be constructed on coordinate paper or transformed to bilogarithmic scale. Sample charts are shown.

186. *On some Seismic Waves with Late Times of Arrival* (In Russian).

A. M. Yepinat'yeva, Akad. Nauk SSSR Izv., Ser. geofiz. No. 6, pp. 21-38, 1952.

In seismic reflection surveys, quite often waves are recorded with exceedingly late times of arrival. If such waves are interpreted as simple reflections, the reflecting boundaries should be at depths of 200 km or more, which is improbable. This paper analyses dynamic characteristics of these waves, primarily the variation of amplitudes with distance, using as a criterion the expression 'At' (where 'A' is amplitude and 't' is time of arrival). If 'At' increases or remains constant over a short distance, then it can be concluded that the waves are not simple reflections. In the absence of strong waves which can be clearly traced over long distances, not much reliance is to be placed on the seismic reflection method.

187. *The Recognition of Refraction in Seismic Reflection Surveying* (In German).

J. de Caley, H. Closs and H. Dürbaum, *Erdöl u. Kohle*, Vol. 5, No. 12, pp. 765-768, 1952.

A new graphoanalytic method of analyzing seismic reflection data is presented that takes into account the variation of seismic velocity and is applicable to inclined strata. The method is discussed first for the case of two formations with different seismic velocities and later extended to any number of layers. It is illustrated by an example of a profile composed of four layers with different velocities in each.

188. *Weathering Corrections in Seismic Refraction* (In Brazilian).

L. Mota, Univ. Brasil Escola da Minas Rev., Vol. 16, No. 5, pp. 35-38, 1951.

Calculation of weathering corrections for cases of one or more inclined refracting layers is described.

189. *Interpretation of Seismic Data on Locating Reefs in Alberta.*

P. I. Bediz, *World Oil*, Vol. 136, No. 2, pp. 86-90, 1953.

Specialized instrumental, shooting, and interpretive techniques are required to locate reefs in the Alberta Devonian formations, which usually give poor reflections characterized by phasing and splitting, abnormal step-out, and the appearance and disappearance of reflections. Pre-Devonian faulting, the lack of Devonian reflections

in areas of other good reflections, and isopach maps for time differences between Cretaceous horizons and the top of the Devonian may all indicate reefs. However, similar conditions can be caused by other sources such as the Paleozoic unconformity.

SEISMIC — THEORY & RESEARCH

190. *Measurement of Travel-Times on Drill-Cores and Rock Samples by Means of Electronics.*

H. Baule, *Geophysical Prospecting*, Vol. 1, No. 2, pp. 111-124, June, 1953.

Supersonic pulses are transmitted into rock samples and cylindrical drill cores of about 10 cm. to about 100 cm. in length by a magnetostrictive driver attached to one end. The pulses are received at any chosen distance along the core by a small crystal geophone resting on the specimen. The beginning of the supersonic pulse and the waveform of the received disturbance, together with the marks of an accurate timer by a quartz clock, are made visual and stationary on the screen of a cathode-ray oscillograph and the travel-time is measured. Thus the core is picked up at different distances and a travel-time curve is drawn from which the velocity of the waves is determined.

The method is interpreted and the measuring device described. Graphs give several travel-time curves of different rock samples, drill cores, metal rods and rods of other solid materials. The elastic moduli 'E' of the samples are communicated, and an example is given for determining Poisson's ratio 'δ' from longitudinal and transverse velocities on two cores of sandstone.

191. *Surface Motion Associated with Obliquely Incident Elastic Waves.*

J. Pearson & J. S. Rinehart, *J. Acoust. Soc. Amer.*, 25, pp. 217-219, March, 1953.

Particle motion at the free surface of a body is deduced by using well-known laws which govern the reflection of elastic waves striking free surfaces obliquely. This motion is represented by diagrams and graphs for the case of an incident longitudinal wave. For oblique incidence, considerations indicate that particle motion at the surface will not, in general, be perpendicular to the surface but will depend on the angle of incidence and the Poisson's ratio of the material. The data are expected to be of value in the solution of problems connected with impulsively loaded bodies such as metal-explosive systems.

192. *The Propagation of a Pulse between Plane Parallel Plates.*

D. V. Anderson, *J. Acoust. Soc. Amer.*, 25, pp. 154, January, 1953.

The theory involved is similar to that of a pulse propagated through a circular cylinder. Experiments carried out on water confined between two parallel plates have been carried out and the agreement with the theory is shown pictorially.

193. *Experimental Technique used to measure Transient Waves through Solids.*

W. A. Allen & C. L. McCrary, *Rev. Sci. Instr.*, Vol. 24, pp. 165-171, Feb., 1953.

An experimental technique, based on the principle of the optical lever, has been used to measure surface oscillations as small as $10\ \mu$ in amplitude on a thick circular plate, while it deforms under explosive attack. The transient behaviour of the plate was determined by means of a long focal-length, sweeping-image camera with a writing speed of $4\ \text{mm}/\mu\ \text{sec}$. In comparison with the Hopkinson method, the technique yields more information of equivalent, or greater, accuracy. Equations are derived that have been used in the analysis of the experimental data. Experimental results are given as an indication of the precision of the technique.

194. *The Possibility of using Shear Waves in Applied Seismic Prospecting (In French).*

Linsser, A Paper read at the 19th International Geological Congress at Algiers, Algeria, Sept., 1952. (Not yet published).

Some of the possible applications of shear waves in seismic prospecting are pointed out. A method of generating these waves is described. The laws of propagation in a homogeneous medium are discussed. The absorption of shear waves is studied, and it is shown how a structure may be delineated.

195. *A Method of Determining the Difference between the Coefficients of Absorption of Seismic Waves* (In Russian).

A. M. Yepinat'yeva, Akad. Nauk SSSR Izv., Ser. Geofiz., No. 3, pp. 70-77, 1952.

The coefficient of absorption of seismic waves propagating through a formation can be an indication of the formation, but its determination is not always possible. The use of differences between these coefficients as an indicative property of adjacent formations is discussed.

196. *Seismic Waves in Vertically Stratified Medium* (In Russian).

I. S. Berson, Akad. Nauk SSSR Izv., Ser. Geofiz., No. 3, pp. 3-33, 1952.

An analysis is made of kinematic conditions which control seismic waves produced in a vertically stratified medium, both overlain by a horizontal layer or extending to the surface of the earth. Travel time curves are constructed for a number of waves corresponding to profiles in different directions. The computed travel time curves are compared with those actually observed over areas of known geology, and good agreement is found between them. In a vertically stratified area, additional types of waves can be generated, such as laterally refracted waves.

Instrument arrangements necessary for obtaining clear structural details are described.

197. *Segment of the Travel-Time Curve of Refracted Waves* (In Russian).

V. A. Bugaylo, Akad. Nauk SSSR, Ural'skiy Filial, Trudy Gorno-Geol. Inst., No. 19, Geofiz. Sbornik No. 1, pp. 14-21, 1950.

In a stratified medium with different velocities in each layer, the traveltime curve becomes a sequence of segments, differently inclined to the 'x'-axis. Following the method of G. A. Gamburtsev, the author derives equations first for the fourth and fifth segments, and then presents a generalization of formulae for the 'n'th segment. The assumption is that seismic velocity increases monotonically with depth and that boundaries between layers are plane, though differently inclined to the horizontal and with the angle of inclination increasing with depth.

198. *On Multiple Refracted Waves* (In Russian).

I. S. Berson, Akad. Nauk SSSR Izv., Ser. Geofiz., No. 4, pp. 9-32, 1952.

A theoretical study has been made of the various kinds of multiple reflection and refraction on the basis of kinematic and dynamic relations determined by the angle of incidence, the ratios of velocities, and similar factors. Two criteria are established which can aid in the recognition of multiple refracted waves when the refracting and reflecting surfaces are planes parallel to the surface: the travel time curves are parallel to the simple refracted waves, and the form of the simple and multiple refracted waves are similar, though sometimes of opposite phase. Comparison of amplitudes does not give reliable information.

199. *Results of Experimental Investigations of Resonance Phenomena in the Vibrating System Ground-Seismograph* (In Russian).

I. P. Pasechnik, Akad. Nauk SSSR Izv., Ser. Geofiz., No. 3, pp. 34-57, 1952.

The effect of the placing of the seismograph on the ground has been investigated.

Field tests were made consisting of the determination of the natural frequency and damping coefficient of vibrating ground-seismograph system as influenced by the properties of the ground, and by the replacement of the instrument (as on the ground, or in a hole), and details of instrument construction, such as the shape of the bottom, ratio between immovable and movable masses, and similar factors. Results are presented in graphical form.

200. *Comparison of the Results of a Theoretical Study of Resonance Phenomena in the System Ground-Seismograph with Experimental Data* (In Russian).

I. P. Pasechnik, Akad. Nauk SSSR Izv., Ser. Geofiz., No. 5, pp. 25-40, 1952.

A theoretical study of resonant properties inherent in the elastic system ground-seismograph. The precise and approximate methods are compared and it is found that there is little difference in the results whereas the latter is more convenient to use. For the approximate method, an alignment chart is constructed giving the frequency of natural oscillations of the ground-seismograph system as a function of the seismic velocity of the ground, its density, the mass of the instrument, and the dimensions of its bottom area. In starting seismic measurements in an area it is important to adjust the mass of the instrument and its bottom area so that the resulting natural frequency becomes sufficiently different from the frequency of observed waves.

201. *Some Problems of Seismic Exploration* (In Japanese with English Summary).

M. Hayakawa, Geol. Survey of Japan Report 137, p. 68, 1951.

The frequency, damping, and sensitivity characteristics of the Haeno seismograph are considered and the instrument is used to demonstrate the occurrence of transverse waves, calculation of surface layer depths, and correlation of distance-amplitude-graph characteristics with geologic structures.

An improved 'contour method' of plotting the results of fan shooting is proposed. Also considered are: the concentration of explosive energy in certain directions, the effect of low velocity layers, the anisotropy of rock formations, and the possible detection of very thin layers.

202. *Frontal Microseisms*.

M. H. Gilmore, Amer. Meteorol. Soc. Bull., Vol. 32, No. 11, pp. 346 & 355, 1951.

Data concerning frontal microseisms, together with data concerning tropical storm microseisms, lead to the conclusion that most microseismic storms are a direct function of the wind force, the density of the air mass involved and the area over which the force acts. Most reliable sources of information also lead to the conclusion that microseismic storms are generated on the ocean bottom directly under the storm area, probably by means of compressional waves set up by the storm.

203. *Generation of Love and other 'SH'-Waves in Study on Surface Waves, Part 6*.

Y. Sato, Tokyo Univ. Earthquake Research Inst. Bull., Vol. 30, Pt. 2, pp. 101-119, 1952.

It is shown that for 'SH' waves the strength of a source at a point and the displacement at another point are connected by a reciprocal formula when both points are in a superficial layer or when one point is in the lower semi-infinite medium. When a periodic source is located in the superficial layer the refracted 'SH' waves propagated in the lower medium ordinarily decrease in amplitude as the inverse $3/2$ power of the horizontal distance from the source; however, predominant 'SH' waves decrease in amplitude as the inverse $1/2$ power of the distance. There are no reflected 'SH' waves from a harmonic source. The amplitude function for Love waves is evaluated for certain elastic parameter values and plotted against velocity and period. It is concluded that large displacements belonging to the branch of Love waves with nodes in the layer cannot be expected.

204. *Distribution of Surface Stress Generating no Rayleigh Waves.*

Y. Sato, Tokyo Univ. Earthquake Research Inst. Bull., Vol. 29, Pt. 3, pp. 445-453, 1951.

This paper demonstrates the manner in which surface stress can be applied to a semi-infinite elastic medium without generating Rayleigh waves. The problem is of practical importance in seismic prospecting where surface waves often obliterate later useful phases of the 'P' group. The condition for nongeneration of Rayleigh waves is set up in terms of a function which depends upon the Poisson ratio. An example of a simple harmonic surface-stress distribution satisfying the condition is given. If the origin is of an aperiodic type, examples can be found in which the condition is only approximately satisfied.

205. *On Rayleigh Wave Velocities.*

L. Knopoff, Seismol. Soc. Amer. Bull., Vol. 42, No. 4, pp. 307-8, 1952.

The values of Rayleigh-wave velocities for materials which do not meet the condition $\nu = 1/4$, have been determined. Deviations from $.9194 V_s$, obtained when $\nu = 1/4$, are not great but are significant in the problem of the identification of seismic wave components at positions close to a source.

206. *Theory of the Hinged Seismometer with Support in General Motion.*

P. Byerly, Seismol. Soc. Amer. Bull., Vol. 42, No. 3, pp. 251-261, 1952.

The purpose of this investigation was to ascertain the relative magnitude of terms normally neglected in writing the equation of the seismograph. These involve rotations of the support and accelerations at right angles to the principal forcing acceleration. The discussion is mathematical. Seven conditions under which these terms may be neglected are given.

207. *The Response of Strain and Pendulum Seismographs to Surface Waves.*

H. Benioff & B. Gutenberg, Seismol. Soc. Amer. Bull., Vol. 42, No. 3, pp. 229-237, 1952.

Investigations at Pasadena show certain advantages gained from the use of strain seismographs and vectorial recorders. The relationship between the response of strain and pendulum seismographs is well adapted to demonstrate the characteristic elliptical motion of the ground particles in Rayleigh waves. More detailed investigations of the effect of crustal inhomogeneities on surface waves are needed. It should be possible to use the vectorial recorder with vertical- and horizontal-pendulum seismometers or with vertical-pendulum and horizontal-strain seismometers to determine the actual shape of the Rayleigh-wave ellipses and the inclination of their major axes. Preliminary investigations suggest that the major axis may be inclined slightly to the vertical.

208. *Energy of the Seismic Waves Reflected and Refracted at a Rock-Water Boundary.*

K. Ergin, Seismol. Soc. Amer. Bull., Vol. 42, No. 4, pp. 349-373, 1952.

Energy ratios of seismic waves reflected and refracted at a rock-water boundary have been computed and are shown in graphs and tables. Poisson's ratios in the solid medium is a dominant factor in the behaviour of reflected and refracted waves in the solid medium. Density has little effect. Peculiar effects are observed near the critical angles of incidence. At the critical angle all energy goes into the reflected wave of the same kind as the incident wave. In all cases, most energy goes into reflected 'P' and 'S' waves because of the contrast in densities and velocities in the two media.

209. *The Calculations of Reflecting Surfaces in Reflection Seismic Surveying (In Italian).*

C. Contini, Ann. Geofis., Vol. 5, No. 1, pp. 77-95, 1952.

On the basis of seismic exploration and geological data, formulae for the variation of the velocity of longitudinal waves with depth are analyzed, and a formula which gives best agreement with seismic evidence is arrived at.

The influence on seismic velocity of heterogeneity and anisotropy of formations, especially noticeable in areas of folding or steep dips, is also discussed, and the problem of determining the reflecting boundary from seismic data is analyzed.

210. *An Application of the Method of Approximations to Seismic Prospecting* (In German). L. Krouskij, Erdöl u. Kohle, Jahrg. 5, Heft 10, pp. 623-624, 1952.

An iteration procedure which can be applied graphically, is suggested for improving the assumed value of seismic velocity constructions. It can be applied when shooting from one point in two diametrically opposite directions. In the proposed geometric figure three points lie on a straight line only with the correct value of seismic velocity. By making this value intentionally too high or too low, deviations from this line are obtained, making it possible by interpolation to obtain more accurate value of seismic velocity.

211. *Sound Waves observed in Mud-Filled Well after Surface Dynamite Charges*. J. R. Ordning & V. L. Redding, J. Acoust. Soc. Amer., Vol 25, No. 4, pp. 719-726, July, 1953.

An array of three pressure pickups 100 ft. apart covering a vertical range of 200 ft. was used to record sound waves in two wells drilled to depths exceeding 12,000 ft. Dynamite charges were exploded in 80 ft. holes at a distance of 500 ft. from the well-head. A separate charge was fired with the array at each 500 ft. interval in the well. The recorded events were analyzed and found to belong to two categories. The first category includes the pressure pulse arriving at the pick-up by a more or less direct route through the sedimentary rocks. The second consists of events set up in the mud column at points other than adjacent to the pick-up by the compressional wave in the sedimentary rocks. These events then travel through the mud column and are recorded as they pass the pick-up. Anomalies in the hole, such as the ends of casing strings and the bottom of the hole, cause events of larger amplitude than those set up in sections of the hole with no major anomalies.

GRAVITY — GENERAL

212. *Measurements of Gravity in Ireland. Gravity Survey of Central Ireland*. T. Murphy, Dublin Inst. for Advanced Studies Geophys. Mem. 2, Pt. 3, p. 31, 1952.

A gravity survey was made in central Ireland between Dublin and Galway, using a small Graf gravimeter. In all, 266 new stations were established. Conclusions are that the low anomaly areas can be attributed to light sedimentary rocks, the density of the lower Paleozoic or pre-Cambrian rocks is less than 2.67 gm/cm³ because of the existence of granite masses or granitization, the Leinster granite extends westward beneath the Paleozoic sediments, the Galway granite is more extensive than the mapped outcrop, and a large positive Bouguer anomaly north of Dundalk seems to be related to Tertiary igneous activity in the Carlingford peninsula.

213. *Measurements of Gravity in Ireland. Gravity Survey of Ireland North of the Line Sligo-Dundalk*.

A. H. Cook & T. Murphy, Dublin Inst. for Advanced Studies Geophys. Mem. 2, Pt. 4, p. 36, 1952.

Values of gravity were determined at 350 stations to within ± 0.4 mgal. Low Bouguer anomalies were found over granite, whose density was found to be less than the surrounding rocks. The larger granite masses had thicknesses between 14,000

and 43,000 ft. Large Bouguer anomalies in the Carlingford-Mourne area are attributed to bodies with densities of about 3.0 gm/cm^3 at depths greater than 10,000 ft.

214. *Experimental Gravimetric and Magnetic Exploration of the Foreland of Colli Euganei, Part I. Measurements with Torsion Balance and Gravimeter.*

C. Morelli, *Ann. Geofis.*, Vol. 3, No. 4, pp. 523-566, 1950.

An Eötvös torsion balance equipped with photographic recording was used at 20 stations, and 37 stations were occupied with the Western gravimeter, in the plain bounded by Battaglia, Pontelongo and Ponte San Nicolo during a preliminary test of geophysical exploration of the foreland of Colli Euganei. Agreement of results from the two instruments indicates the reliability of the determination of the elements of disturbing gravitational field. The applicability and advantages of the torsion balance are discussed with reference to local conditions. Certain conclusions are suggested as to the roots of Colli Euganei from interpretation of the results.

215. *Gravimetric Survey and Isostatic Reduction in Northeastern Italy* (In Italian).

C. Morelli, *Tecnica Italiano*, Vol. 6, No. 3 & 4, 1951.

A gravimetric survey was made north of the Po River during 1950-51. A Worden and a Western gravimeter was used and a total of 181 stations was occupied. The results are discussed.

216. *First Contribution to Fundamental Gravimetric Network of Italy* (In Italian).

C. Morelli, *Ann. Geofis.* Vol. 5, No. 1, pp. 97-123, 1952.

A regional gravity survey of Italy, including the islands of Sardinia and Sicily was made using two Worden gravimeters. Padova was used as the base station and 41 stations were occupied. The error in final determination of 'g' at individual stations was about $\pm 0.01 \text{ mgal.}$, and closing errors of individual loops was never greater than $\pm 0.12 \text{ mgal.}$

Several tables and a map of the area are given.

217. *Gravity Measurements in Valle Latina and their Geologic Interpretations* (In Italian).
G. Tribalto, G. Zaccara, & Beneo, *Serv. Geol. Italia Boll.*, Vol. 73, No. 2, pp. 357-370, 1952.

During the gravimetric survey in Valle Latina, 188 stations were occupied in an area about 300 sq. km., using a Western gravimeter. Results are presented in tabular and map form. Geological interpretations of the results are given in a separate section.

218. *The Gravity Field of the West-Mediterranean Area.*

B. J. Hofman, *Geol. en Mij.*, Vol. 14, No. 8, pp. 297-306, 1952.

Gravity profiles were computed on the basis of van Bemmelen's geologic map and profiles on indicated densities and compared with gravity measurements at sea, in Spain, northern Africa, France, Italy, and the Balkan Peninsula by different investigators. The agreement between the computed and measured profiles was close. An isogam map on a scale of 1:10,000,000 shows the Hayford-Bowie isostatic anomalies of the western Mediterranean area.

219. *Gravity Profiles across the Canterbury Plains.*

T. Hatherton, *New Zealand J. Sci. Tech.*, Sec. B, Vol. 34, No. 1, pp. 13-20, 1952.

Four gravity profiles were run across the Canterbury Plains on the eastern coast of South Island, New Zealand. Extending sea-ward from this area is the Chatham Rise which separates the Kermadec Trench to the north from the Bounty Basin to the south. The gravity maps and profiles indicate a saddlelike configuration of the basement topography separating landward extensions of the structural trends of

the Kermadec Trench and Bounty Basin. These extensions modify the general structure of the Canterbury Plains syncline. The basement in this area is greywacke, of apparent density 2.65, and is overlain by late Tertiary and recent sediments with a mean density of 2.15. It is assumed that the igneous rocks of Banks Peninsula do not affect the gravity distribution significantly for the basement density is said to be about 2.65.

220. *Gravimetric Survey of Sicily* (In Italian).

E. Medi & C. Morelli, *Ann. Geofis.*, Vol. 5, No. 2, pp. 209-245, 1952.

During 1952 a gravity survey in Sicily used 299 stations, of which 6 were of the first order, and 7 of the second. The principal instruments were two Worden gravimeters. Results are presented in a map of Bouguer anomalies that shows a wide negative anomaly in the central zone of the island and extending into the sea toward the south, surrounded by positive anomalies especially marked toward the southeast. The negative anomaly probably corresponds to a depression in which a great thickness of clays has accumulated. The depression is surrounded by a zone in which the dense substratum is close to the surface or at it in the southeastern part of the island. As the massive flows of Etna have almost no effect on the gravimetric anomalies, it can be concluded that they are confined to the outermost layers of the crust.

221. *Gravimetric Measurements in New Caledonia* (In French).

Y. Crenn, *Acad. Sci. Paris Comptes Rendus*, Vol. 236, No. 1, pp. 105-107, 1953.

A gravimetric survey of New Caledonia, using about 1800 stations, was made with a North American gravimeter. Results are presented as a map of Bouguer anomalies. The anomalies are all positive and range from 60-170 mgals. A minimum elongated parallel to the main axis of the island and increasing under the more mountainous terrain suggests at least partial isostatic compensation. Other anomalies may be associated with peridotitic rocks.

222. *Gravitational Prospecting at Honjo-Fujioka District, Northwest Side of Kanto Plain* (In Japanese with English Summary).

Y. Murakami & K. Katayose, *Geol. Survey Japan Bull.*, Vol. 2, No. 11, pp. 44-63, 1951.

A gravity survey of the northwest part of the Kanto Plain indicated that in general the basement dips toward the north with some irregularities.

223. *Isogal Map of Western Area in Tohoku Region* (In Japanese with English Summary).

Geophys. Expl. Dept., Japan, *Geol. Survey Japan Bull.*, Vol. 3, No. 2, pp. 50-51, 1952.

A gravity survey in parts of Aomori-ken and Akita-ken is described, and results presented as a map.

224. *Preliminary Report on the Geophysical Survey of the Collie Coal Basin.*

N. G. Chamberlain, *Western Australia Geol. Survey Bull.*, No. 105, pp. 157-163, 1952.

A gravimetric survey was made, using the Humble-Truman gravimeter, over an area of more than 100 sq. ml., occupying 767 stations. Results are presented as a map with contour interval of 1 mgal. The configuration of the basin was clearly delineated by the survey.

225. *What Role should Gravity play?*

P. C. Ingals, *Oil & Gas J.*, Vol. 52, No. 4, p. 145, June 1, 1953.

The possible uses and the limitations of gravity surveys are discussed by a problem

panel. No definite rules result, but the exchange of ideas provides valuable guides for specific problems.

226. *Gravity Investigations in North-Central Pennsylvania.*

B. F. Howell, Jr., & K. Vozoff, Trans. Amer. Geophys. Un., Vol. 34, No. 3, pp. 357-359, June, 1953.

A gravity survey of about 900 sq. ml. in Tioga County, Penn., is described. Within this area a positive anomaly of 22 mgals. is observed. It is shown that the greater part of this could be accounted for by the presence of a buried intrusion of diabase or peridotite.

227. *The Earth's Gravitational Field and its Exploitation in Advances in Geophysics.*

G. P. Woollard, New York, Academic Press, Vol. 1, pp. 281-311, 1952.

A review of gravity measurements and their uses in both geodetic and geologic studies.

228. *The Geophysical Applications of Gravity Anomalies.*

W. Heiskanen, Amer. Geophys. Un. Trans., Vol. 34, No. 1, pp. 11-15, 1953.

A discussion on the uses and abuses of gravity anomalies in such geophysical applications as studies of isostasy, thickness of the crust, and behaviour of the earth's interior.

229. *Some Notes concerning the Question of Isostasy* (In Hungarian).

L. Egyed, Acta Tech. Acad. Sci. Hungary, Vol. 4, No. 1-4, pp. 75-84, 1952.

Assuming in principle the Airy-Heiskanen hypothesis of isostatic equilibrium, but also that: the earth's crust consists of two layers of different densities; is partly covered with sediments several kms thick of density less than 2.67; has a certain rigidity; and that the depth of the equilibrium layer is about 50 km; and taking certain densities for the different layers; the pressures at a depth of 50 km are computed at Heligoland, Haslach, and under the Atlantic Ocean.

Similar computations show that over most of the earth's surface isostatic equilibrium exists. However, such equilibrium cannot exist in oceanic areas which have depths of more than 6 km.

230. *Correlations between Gravimetric and Structural Data in the Northern Part of the Province of Alger* (In French).

L. Glangeaud & J. Lagrula, Acad. Sci. Paris Comptes Rendus, Vol. 235, No. 2, pp. 193-196, 1952.

Gravity anomalies here seem to vary with the thickness of the overburden which consists of secondary Tertiary and Quaternary formations. The density decreases with decreasing age, a fact which explains the negative anomalies found in several places. Positive anomalies are attributed to deep anticlines, whose presence and size have been previously established. A still better agreement between the gravitational pattern of the province and geologic details may be obtained if, instead of an average density of 2.67, values corresponding to individual formations are taken.

231. *Gravity Survey in The Congo.*

Nature, Vol. 172, No. 4371, p. 258, August 8, 1953.

The Service of Meteorologie et de Géophysique of the Belgian Congo has started a basic survey of gravity stations, in order to supply a fundamental network to workers engaged in more detailed measurements. The provisional results of the first part of the basic network are presented in tabular form. No corrections for sun and moon tidal variations have yet been made.

232. *Gravity Measurements over the Northern Pennines.*

Geological Magazine, Vol. 90, No. 3, pp. 221-222, May-June, 1953.

Prof. A. Holmes, of the Grant Inst. of Geology, Univ. of Edinburgh, criticises parts of the preliminary account of detailed work in and around Upper Weardale, by M. H. P. Bott and D. Masson-Smith. Prof. Holmes disagrees with their idea of the source of origin of the so-called 'Weardale Granite' and gives his own opinion. Bott and Masson-Smith discuss the points raised by Prof. Holmes in a reply.

GRAVITY — INSTRUMENTAL

233. *Patents. Abstracts in Geophysics, Vol. 18, No. 2, p. 459, April, 1953.*

U.S. 2,613,536. 14 Oct., 1952. Gravity meter having a mass suspended from the middle of a horizontal wire which is connected to a bridge circuit.

U.S. 2,614,432. 21 Oct., 1952. Gravity meter whose mass supporting spring forms part of an electrical circuit.

U.S. 2,618,156. 18 Nov., 1952. Gravity and density gradiometer for boreholes, having suspended beam, cross beam and pair of suspended masses.

234. *An Improved Gravimeter (In German).*

Erdöl & Kohle, Vol. 6, No. 1, p. 54, 1953.

An improved version of the Graf gravimeter has a wide scale and calibration arrangement which permits testing the instrumental constant in every part of the scale and unlike previous models is not an astatic instrument. Photoelectric arrangement increases the sensitivity to better than 0.01 mgal. The instrument is thermally well insulated and is provided with an adjustable thermostat. The new gravimeter constant is better than 0.03 mgal. per division of the scale and the average error of the first readings is about 0.01 mgal.

235. *Apparatus for Aerogravimeter Prospecting.*

C. A. Heiland, U.S. Patent 2,626,525. 27 Jan., 1953.

An automatic levelling gravity measuring device adapted to be lowered to the ground from an aircraft for reading.

236. *Patents. Abstracts in Geophysics, Vol. 18, No. 3, p. 702, July, 1953.*

U.S. 2,626,525. 27 January, 1953. A gravimeter that may be lowered from the air, with automatic levelling.

237. *A Total-Registering String-Suspended Pendulum for the Absolute Determination of Gravity (In German).*

A. Berroth, Geofis. Pura e appl., Vol. 24, pp. 11-36, 1953.

The string supported pendulum has great advantages over others in absolute determinations of gravity, because many usual errors are eliminated and others can be determined by analytical methods or by calibration.

To achieve satisfactory results, comparable with those obtainable with the best ordinary pendulums, it is necessary to find accurate methods of computing these corrections. The effects of several disturbing factors are discussed, special attention being paid to Foucault revolution and to elliptic deviation of the oscillations of the pendulum bob. Final results are presented in a form convenient for numerical calculation of individual errors.

(From Geophysical Abstracts 154, U.S. Geol. Survey).

GRAVITY — INTERPRETATION

238. *On the Interpretation of Gravity.*

A. van Weelden, *Geophysical Prospecting*, Vol. 1, No. 2, pp. 75-81, June, 1953.

In recent years the geological interpretation of gravity data has two schools of thought. The first tries to derive a mass distribution that would explain the observed anomalies with the use of precise mathematical methods, eliminating all personal equation or bias. The second stresses that there are many possible solutions acceptable from a purely mathematical viewpoint; so that other considerations, especially geological ones, are necessary before the best solution can be chosen.

The various mathematical methods are discussed. The author believes that gravity data should be considered only as a source of information, and not self-sufficing. All other available information, geological and geophysical, should be utilised. The necessity for co-operation between the gravity interpreter and the geologist is stressed.

239. *A Least Squares Method for Gravity Meter Base Stations.*

H. H. Pentz, *Geophysics*, Vol. 18, No. 2, pp. 394-400, April, 1953.

Two applications of the method of least squares in determining the most probable values from gravity meter base station applications are considered. One is an approximation, the degree of approximation depending on the number of base stations. The second is a rigorous application of the method of least squares in obtaining the most probable values for an expanding base station network.

240. *Contribution to the Method of Torsion Balance Surveying in Underground.*

Z. Zagorac, *Geophysics*, Vol. 18, No. 2, pp. 448-458, April, 1953.

A manner of interpretation of torsion balance survey in underground is shown, when the gradients U_{xz} , U_{yz} , and the curvature value U_{xy} are measured. Values U_{xy} and U_{xz} are composed as vectors in the vertical plane $Z-Y$; U_{yz} and U_{xy} are composed in the plane $Z-X$. In various examples it is shown that the resulting vectors give a better means of determining the position of ore bodies. An example of actual torsion balance survey in an iron ore mine is given. The method of eliminating the influence of mass irregularities close to the instrument by means of parallel profiles is described and discussed.

241. *New Gravity Approach aids Reef Interpretation.*

R. A. Pohly, *World Oil*, Vol. 136, No. 6, pp. 116-124, May, 1953.

A review of various field procedures and interpretative methods available in the search for reefs.

242. *Direct Methods of Interpretation of Gravitational and Magnetic Anomalies produced by Two-Dimensional Bodies (In Russian).*

I. S. Gel'fand, *Akad. Nauk SSSR, Ural'skiy filial, Trudy Gorno-Geol. Inst., Vypusk 19, Geofiz. Sbornik 1*, pp. 51-63, 1950.

Formulae for direct interpretation of gravitational and magnetic anomalies, which give the mass of the disturbing body, position of its centre, and other features, may be made more convenient for use by the simplification in the computations of pertinent integrals introduced here.

243. *Deflections of the Vertical from Gravity Anomalies.*

D. A. Rice, *Bull. Geod.*, No. 25, pp. 285-312, 1952.

Investigating the accuracy with which deflections of the vertical can be obtained from analysis of gravity variations throughout a somewhat limited area, data from about 40,000 gravity stations in an area of 800,000 sq. ml. were used. Agreements of

the order of 1 sec. were obtained between astronomic-geodetic and gravimetric deflections using gravity fields limited to a radius of 150 km. In extending the radius to 500 or 600 km, the gravimetric deflection changed by 1 to 2 secs and at 600 km the gravimetric deflections appeared to approach absolute values within about 1 sec.

244. *The Topographic Correction in Gravimetric Investigations* (In Spanish).

J. Garcia Sineriz, Rev. Geofis. Vol. 11, No. 41, pp. 1-17, 1952.

A method of computing the topographic correction of gravity determinations is discussed. The procedure consists of determining the gravitational effect of annular masses of increasing radii around the station divided into sectors of different angular openings, and summing up these effects. The attainable accuracy of the computations is influenced by the differences in elevation, and the precision and scale of available maps of the region.

Convenient forms and practical rules for necessary computations are worked out, and recommendations are given for the selection of appropriate station sites.

245. *Direct Methods of Interpretation of Gravitational and Magnetic Anomalies produced by Three dimensional bodies* (In Russian).

I. S. Gelfand, Akad. Nauk SSSR, Ural'skiy filial, Trudy Gorno-Geol. Inst., vyp. 19, Geofiz. Sbornik 1, pp. 64-80, 1950.

The total mass and the centre of gravity of a buried body can be found from observed gravity anomalies and gravity gradients; similar parameters of a magnetic mass can be determined from the observed components of magnetic vector. This, however, necessitates lengthy evaluation of double integrals in the formulae and is therefore seldom used. More convenient formulae for the computations of these integrals are derived, and the limits of errors which would effect the results if certain approximations are admitted were determined.

246. *The First Order Terms of the Indirect Effect* (In French).

J. Goguel, Ann. Geophys., Tome 7, No. 3, pp. 169-174, 1951.

In Vening Meinesz's system of linear equations for each of the terms of the harmonic analysis of the topography, the system of axes used implicitly has as its centre the centre of concentric spheroidal surfaces. While this holds for the terms of the second and higher order, it leads to an ambiguity in the case of the first order harmonic. The ambiguity can be eliminated by taking as the centre a point which, where the interior of the sphere is concerned, appears to be the centre of attraction. Calculations show that this point is the correct centre of reference for the co-ordinates of first-order terms. (From Geophysical Abstracts 154, U.S. Geol. Survey).

247. *Contribution to the Interpretation of Gravity Pictures by means of Higher Derivatives* (In German).

B. Kosbahr, Geophysical Prospecting, Vol. 1, No. 4, pp. 250-258, Dec. 1953.

For the treatment of the problems involved in the interpretation of gravity pictures this paper gives a formula that holds generally for any potential function. It provides an extended applicability of the relation used by Elkins for the computation of the second derivative, and also yields an analogous relation to derivatives of higher order of the gravity field.

This relation has not been utilized to determine in detail the course of the derivatives of higher order in a plane, but is merely applied to points of comparatively extreme curvature of the isogams where the differential values present a ratio favourable to the "noise level". By this method the values of the derivatives of higher order will not be determined themselves but only the ratios responsible for the depth of divergence in comparison with the course of an anomaly of masses replaced by points.

It is shown by examples of intercalated masses that the divergence points are important and by law related to the form and position of the density contrasts themselves.

An analysis of the total gravity picture is made possible by progressing from elements close to the surface to deeper ones. In this way the fundamental features of the earth's crust will be obtained. The application of the analysis process to a gravity anomaly actually measured in Northwest Germany is given.

GRAVITY — THEORY AND RESEARCH

248. *Relations Between Electrical and Gravity Anomalies* (In Russian).

Iu. P. Bulashevich, Akad. Nauk SSSR. Ural'skiy Filial, Trudy Gorno-Geol. Inst., Vyp. 19, Geofiz. Sbornik, No. 1, pp. 3-13, 1950.

Certain relations between gravity and magnetic anomalies have been long established. In the present study approximate correlations are established between electrical anomalies in a homogeneous field and corresponding magnetic anomalies and through them with gravity anomalies. This correlation is valid, however, only under certain conditions as to the shape and density of distributing body and the constancy of magnetizing field. The derivation is made by replacement in the potential equation of magnetic susceptibility by dielectric constant and of the intensity of magnetic field by that of electrostatic field. The effects of the boundary surface ground-air on data characterizing the electric field, and the necessary corrections, are also discussed.

249. *Divergence of the Surface Gradient of Gravity* (In Italian).

A. Marussi, Geofis. Pura e Appl., Vol. 25, pp. 1-5, 1953.

In some modern procedures for the study of gravity anomalies, the divergence of the surface gradient of gravity on a level surface is considered. Such divergence is connected with the geometrical and dynamical elements of the field by simple relations, in particular to with second derivatives of gravity along the lines of force. In this paper the general formulae are applied to Somigliana's field referred to its intrinsic coordinates, and the values of the surface divergence and other elements of the normal field are given from 10° in latitude.

250. *Non-Elastic Tilt of the Earth's Crust due to Meteorological Pressure Distributions*. R. Tomaschek, Geofis. Pura e Appl., Vol. 25, pp. 17-25, 1953.

A typical disturbance observed in the records of tilt measurements performed with horizontal pendulums in a mine at a depth of 145 m below surface, under very constant temperature conditions, has been analysed as to its correlation with the barometric pressure distribution. It is shown that the observed load tilts are not due to elastic deformations of the Earth's crust, but may be ascribed to movements of tectonic blocks of large extension.

251. *The Effect of Sun and Moon on Gravitational Measurements* (In Hungarian with English Summary).

K. Lassovsky & S. Oszlaczky, Magyar Allami Eötvös Lorand Geofiz. Intezet Geofiz. Közlemenyek, Kötet 1, Szam 3, pp. 13-29, 1952.

In their studies of lunar-solar effects on terrestrial gravity the authors took into account parallactic effect and computed, by the methods of celestial mechanics, the disturbing effect of the moon and sun on gravity measurements in Budapest. During August and September, 1951, precise determinations of gravity were made using two Heiland gravimeters. The observed values were compared with computed values, the difference being the measure of the deformation of the earth due to tidal effect. The

mean value of the ratio of observed tidal variations to theoretical values for a rigid earth was calculated as 1:16.

252. *Isostatic Compensation of the Continents and Oceans as a Whole* (In French).

A. Cailleux, *Rev. Gen. Sci. Pur. et Appl.*, Tome 59, No. 1-2, pp. 3-5, 1952.

The thickness of suboceanic sial, according to Wegener, is calculated on the basis of several other hypotheses and found to range from 6 to 20 km. No matter which pair of values are adopted for density and depth, all theories lead to contradictions which cannot be resolved without resorting to other hypotheses. These values thus seem to have only regional rather than worldwide significance.

253. *Theoretical Investigation of the Problem of Isostasy* (In German).

O. Rosenbach, *Geofis. Pura e Appl.*, vol. 22, Fasc. 1-2, pp. 1-36, 1952.

Pratt's and Airy's hypotheses of isostasy are analyzed and the conclusion is reached that it is possible that an infinite number of "gravimetrically equivalent" structures of the crust could produce identical results. Therefore, only by supplementing gravimetric data with seismologic evidence and general geologic considerations is it possible to clarify the problem of isostasy.

254. *Experimental Investigations with the Norgaardgravimeter TNK 1427* (In Hungarian with English summary).

R. H. Haazne, *Magyar Allami Eötvös Lorand Geofiz. Intezet Geofiz. Közlemenyek*, Kötet 1, Szam 8, pp. 74-80, 1952.

Extended experiments were made both in the laboratory and in the field, to check the functioning of this gravimeter. These experiments have immediately established the impossibility of dispensing with a thermostat. No azimuthal or magnetic effects on this gravimeter were detected. Drift of the zero point was positive in the laboratory, being 1 to 2 mgal per day at 20 C, and 4 to 5 mgal at 40 C. In the field the drift sometimes became negative. The mean error of an observation was found to be 0.11 mgal, that of mean values equal to 0.05 mgal. The results of the experiments are presented on tables and in graphs.

MAGNETIC — GENERAL

255. *Geomagnetic Survey in Williston Basin ... Rolette & Towner Counties, North Dakota*. N. N. Kohanowski, *Oil & Gas J.*, Vol. 50, No. 50, pp. 127-8, April 21, 1952.

The survey was designed to obtain a general idea of possible subsurface structures. It was commenced towards the end of June, 1951, and finished at the end of August. From the resulting geomagnetic map, the conclusions are:

- (1) There is a definite geomagnetic gradient to the southwest, which may be interpreted as a gradual thickening of sedimentary strata in that direction.
- (2) In the area of the Turtle Mountains, a fairly uniform spacing of isogammas indicated lack of structure. The instrument used for the survey was a Schmidt-type vertical intensity magnetometer.

256. *Measurements of the Variation with Depth of the Main Geomagnetic Field*.

S. K. Runcorn, A. C. Benson, A. F. Moore & D. H. Griffiths, *Roy. Soc. London Phil. Trans.*, Ser. A, Vol. 244, No. 878, pp. 113-151, 1951.

The main geomagnetic field is attributable either to phenomena within the core or to a fundamental property of rotating matter in which the source of the field is distributed throughout the earth. Core theory predicts an increase in the horizontal component with depth while the distributed theory predicts a decrease. This paper

reports experiments made in 5 deep mines in England in an attempt to distinguish between the two theories. A detailed discussion is given of the geologic factors affecting the problem and of corrections applied to account for local anomalies and anomalous gradients. The results provide evidence preponderantly in favour of core theory.

257. *Aeromagnetic Surveying in Advances in Geophysics.*

J. R. Balsley, New York Academic Press, Vol. 1, pp. 314-349, 1952.

Instrumentation, field and office techniques, interpretation of results, advantages and limitations, and uses of aeromagnetic surveying are reviewed.

258. *Results of Magnetic Observations made between 1934 and 1938 for the Setting Up of the Magnetic Map of Belgian Congo* (In French).

L. Hermans, Inst. Roy. Colonial Belge Mem., Vol. 5, No. 3, p. 67, 1951.

Data on stations occupied and magnetic observations in the region between longitudes 22.5 and 27.5 east and between latitude 0.5 south and the southern border of the Belgian Congo.

259. *Magnetic Survey of New Zealand at epoch 1st July, 1945.*

H. F. Baird & A. L. Cullington, New Zealand Dept. Sci. Indus. Researchs, Geophys. Mem. 1, p. 54, 1952.

Results of a magnetic survey of New Zealand and its outlying islands, carried out between 1941 and 1948, using an earth inductor magnetometer. Declination, horizontal force, and inclination were observed and collated with simultaneous D, H, and I traces on the Amberley magnetograms from Amberley. A list of 219 stations with their data is given; 7 isomagnetic charts for declination and inclination, and for horizontal, vertical, total, northerly, and easterly forces, are appended.

260. *Causes of the Magnetic properties of Certain Soils* (In French).

S. Henin & E. Le Borgne, C. R. Acad. Sci. (Paris) 236, pp. 736-8, Feb. 16, 1953.

Certain soils contain a much higher magnetic susceptibility than the rocks from which they are derived. Granulometric analysis indicates that this property resides mainly in the smallest grain component, i.e. in the clay. The agent responsible does not seem to be magnetite; a suggestion is made as to what it might be.

261. *Magnetic Exploration for Chromite.*

H. E. Hawkes, U.S. Geol. Survey Bull., Vol. 973-A, pp. 1-21, 1951.

This paper summarizes the problem of magnetic exploration for chromite, reviews the published literature on the subject, and presents the results of experimental surveys by the author in 1941 on some of the more important chromite deposits of the western United States.

262. *Magnetic Properties of the Earth's Interior.*

A. T. Price, Nature, Vol. 172, No. 4383, pp. 786-787, Oct. 31, 1953.

A discussion on the magnetic properties of the earth's interior was held at a meeting of the British Association on September 4th, at Liverpool.

263. *Magnetometric Mapping for Haematite in South Wales.*

C. R. K. Blundell, Geological Magazine, Vol. 90, No. 1, pp. 57-64, 1953.

In the search for large deposits of haematite and other feebly magnetic minerals it is suggested that mapping the magnetic residuals may be of greater value than mere linear traverses. Not only is the method more suitable for exploring virgin areas but it also affords a means of differentiating between the effects of large deeply buried

masses and small objects at shallow depths. At the same time the graphical expression of the results on the map becomes more easily intelligible. The application of the method at known haematite ore bodies in South Wales has yielded striking results, and the extension of the survey into an unexplored area indicates the possibility of proving at least one further large haematite deposit.

MAGNETIC — INSTRUMENTAL

264. *Reconnaissance Magnetometer.*

Technical Developments, Petroleum, Vol. 16, No. 7, p. 202, July, 1953.

The B-2 Magnetometer, recently developed in the U.S.A., is a light-weight, direct-reading magnet balance designed primarily for reconnaissance prospecting. Sensitivity is claimed to be of the order of 40 gamma per division and is fairly linear across the scale from +30 divisions. It incorporates all the features of a Schmidt-type vertical magnetometer, including latitude and temperature compensation, and, in addition, is equipped with attached compass and levelling head assembly. This type of magnetometer is said to be as easy to read as a dip needle and the total weight of instrument and tripod is only 5 lb.

The instrument has been developed to ground-check airborne magnetic maps or generally delineate structures with high magnetic characteristics.

265. *Airborne Magnetometer for Determining all Magnetic Components.*

E. O. Schonstedt & H. R. Irons, Trans. Amer. Geophys. Un., Vol. 34, No. 3, pp. 363-378, June, 1953.

The NOL vector airborne magnetometer Type 1A (VAM-1A), designed for measuring components of the geomagnetic field from aircraft, consists of a modification of the AN/ASQ-3A equipment employed for geophysical exploration by air. The VAM-1A continuously records the total intensity of the field and its direction with respect to vertical and horizontal coordinates established by a pendulum. The effects of accelerations of the aircraft on the vertical accuracy of the pendular reference are largely eliminated by averaging the magnetometer data over a period normally required for two phugoid oscillations of the aircraft. The operation of the magnetometer is limited to regions in which the magnetic dip exceeds 45°. The magnetometer is estimated to measure F, H, and Z to an accuracy of 200 gammas.

266. *A New Kind of Platform for measuring the Vertical Gradient of Anomalous Magnetic Fields with a Magnetic Field Balance* (In Russian).

M. F. Nodya, Akad. Nauk Gruzinsk. SSR Soobscheniya, Vol. 12, No. 3, pp. 135-138, 1951.

The vertical gradient of the magnetic field is usually determined by measuring vertical magnetic component at different heights. In practice this height is seldom greater than 2 or 3 m and the measurements are made by using a special portable trestle. The author designed two easily portable trestles, one for the instrument, another for the observer. The latter can be made very light and not necessarily rigid. The use of two separate platforms greatly reduced the weight of the trestles, bringing them down to only 25 kg, a weight which can be easily transported even in mountainous country.

267. *On the Magnetic 'H'-Balance for the Galathea Deep-Sea Expedition.*

J. Egedal, Geofis. Pura e Appl., Vol. 25, pp. 26-28, 1953.

The principles of the 'H'-balance for magnetic deep-sea measurements are mentioned, and the qualities of the balance are discussed.

268. *Patents.* Abstracts in Geophysics, Vol. 18, No. 3, p. 702, July, 1953.

- U.S. 2,624,778. 6 January, 1953. A magnetic gradiometer having a pair of spatially-separated opposing coils which are moved in the magnetic field.
- U.S. 2,627,542. 3 February, 1953. Vertical component magnetometer.
- U.S. 2,629,003. 17 February, 1953. Magnetic force-balance type of magnetometer.
- U.S. 2,632,883. 24 March, 1953. Flux-valve type magnetic detector.
- U.S. 2,632,884. 24 March, 1953. Self-orienting total-field magnetometer.
269. *The Airborne Magnetometer* (In Spanish).
J. Borrego Gonzalez, Inst. Geol. Min. España, Notas y Coms., No. 26, pp. 79-88, 1952.
A brief description of the construction and the use of the airborne magnetometer and its advantages in mineral prospecting.
270. *The Initial Adjustments of Vertical Variometers*.
J. M. Bruckshaw, Geophysical Prospecting, Vol. 1, No. 4, pp. 259-271, December, 1953.
Using a comprehensive theory of the vertical force variometer, it is shown that the mean of the two readings taken in azimuths 180 degrees apart only eliminates the error of misorientation and of inclination of the knife edge if these factors are sufficiently small. The necessary accuracy in the 180 degrees rotation and in the readjustment of the levels are investigated and a practical test is developed to allow the initial adjustments to be determined. Finally, a brief description of a new variometer tripod is given.
271. *New Instruments for Magnetic Exploration* (In Russian).
Ye. V. Karus, Akad. Nauk SSSR Izv. Geofiz., No. 3, p. 285, 1953.
A brief review of new instruments for magnetic investigations that have been tested in the Akad. Nauk Geofiz. Institute. Among them is an apparatus for determination of the magnetic properties of formations in a drill hole. The method is based on measurements, using a photoelectric fluxmeter, of the variation of remanent magnetism in a permanent magnet and of the increase in intensity of the total magnetic flux. A magnetometer adapted for field work has been constructed for measuring and recording magnetic field vectors in any desired direction with a sensitivity as high as 20×10^{-5} oersted per mm of scale.

(From Geophysical Abstracts 154, U.S. Geol. Survey).

MAGNETIC — INTERPRETATION

272. *Evaluation of Anomalies by Derivatives*.
H. W. Hoylman, a paper read at the 6th Annual Midwestern meeting of the S.E.G. at Fort Worth, Texas, Nov., 1952. (Not yet published).
Use if made of second and fourth derivatives in the delineation and evaluation of anomalies in aeromagnetic surveys. The second derivative provides delineation on a regional basis, whereas the fourth derivative provides a semi-detailed delineation plus a statistical rather than a personal evaluation of anomalies. Correlation is shown of typical fourth derivative anomalies with three Devonian oil fields in New Mexico.
273. *Reduction of Airborne Magnetometer Results*.
L. Hurwitz, Trans. Amer. Geophys. Un., Vol. 34, No. 3, pp. 360-362, June, 1953.
Reductions of observations obtained with the vector airborne magnetometer, Model 1A, is somewhat simplified by the computation of reduced (level flight) angles. Aircraft swing data are analysed by magnetic field components X , Y , Z rather than by elements D , H , Z . Similarly corrections for aircraft magnetism are applied to components, thus facilitating the application of punch-card processing methods.

274. *Reduction of Magnetic-Field Data, (using Punched-Card Equipment).*
P. Knaplund, P. Fullerton & E. Ford, Oil & Gas J., Vol. 52, No. 9, pp. 70-71, July 6, 1953.
In the reduction of magnetic field data the manual re-entry of numbers is eliminated. The calculation of the second vertical derivative of magnetic intensity using three rings on a rectangular grid illustrates a use for punched-card equipment. Shape of grid, number of rings, and weighting factors may be varied at will.
275. *Direct Methods of Interpretation of Gravitational and Magnetic Anomalies produced by Two-Dimensional Bodies* (In Russian).
I. S. Gel'fand, Akad. Nauk SSSR, Ural'skiy filial, Trudy-Gorno-Geol. Inst., Vypusk 19, Geofiz Sbornik 1, pp. 51-63, 1950.
Formulae for direct interpretation of gravitational and magnetic anomalies, which give the mass of the disturbing body, position of its centre, and other features, may be made more convenient for use by the simplification in the computations of pertinent integrals introduced here.
276. *Determination of the Intensity and Direction of the Magnetization of Disturbing Bodies from the Data of Magnetic and Gravimetric Surveys* (In Russian).
D. S. Mikov, Akad. Nauk SSSR Izv., Ser. Geofiz., No. 5, pp. 55-56, 1952.
A method is presented of finding by theoretical calculations the intensity and the direction of the magnetization of a buried body from the data obtained by gravity and magnetic measurements. The disturbing body is assumed to be homogeneously magnetized.
Necessary formulae are derived correlating magnetic and gravity anomalies, first for 3- and 2- dimensional bodies with vertical magnetization; later extended to a 2-dimensional body with inclined magnetic axis. Such relations can be established for any point on the surface of the earth. By repeating the procedure for several points and averaging the results, it is possible to improve the accuracy.
277. *Magnetic Data from Sedimentary Beds.*
J. L. Harper, Petroleum Engineer, Vol. 25, No. 9, pp. B38-43, August, 1953.
An experimental table for purposes of laboratory practice is described. Its use would provide a knowledge of the resulting complex curves that cannot be obtained by theoretical study. Results of experiments with the table show how sedimentary formations carrying magnetized beds may be used as datum.
278. *On the Mathematic and Geologic Interpretation of Magnetic Anomalies.*
G. Törnquist, Acad. Aboensis Acta, Math. Phys. 18, No. 2, p. 120, 1952.
After a short introduction dealing with fundamental principles of magnetism and magnetic measurements, computations are given of the characteristics of the fields generated by a magnetic pole, vertical double pole, inclined double pole, linear configurations differently placed, and of combinations of these elements. These are followed by a discussion of the magnetic fields produced by a sphere, cylinder, ellipsoid of revolution, two-dimensional bodies in general, elliptic cylinder, and plate. Tables of numerical data for special geometric conditions, which are also illustrated by graphs, are given. Several practical examples of the use of the formulae and graphs are included.
The article also contains a table of magnetic data of different rocks and a theoretical discussion of the correlation between magnetic and gravitational anomalies.

MAGNETIC — THEORY & RESEARCH

279. *On the Origin of Inversions of Magnetization found in Rocks in the Auvergne* (In French).

A. Roche, C. R. Acad. Sci. (Paris), Vol. 236, pp. 107-109, Jan. 5, 1953.

Experiments on lava specimens and their underlying clays suggest that the reversed magnetizations are not due to any mechanism inherent in the nature of the rocks themselves, but originate from the geomagnetic field itself being reversed at the time the rocks were laid down.

280. *Magnetic Susceptibility Measurements in Minnesota.*
(Part II: Analysis of Field Results).

H. M. Mooney & R. Bleifuss, Geophysics, Vol. 18, No. 2, pp. 383-393, April, 1953.

75 samples of 7 rock types have been analysed for magnetite content by magnetic separation and chemical analysis, making allowance for iron which occurs as ilmenite, hematite, and silicates. Magnetic susceptibility shows a clear dependence on magnetite content but with too much scatter to permit prediction of one from the other. For small magnetite content V (in volume percent), susceptibility k is roughly given by $k = 3000 \times 10^{-6} V$ cgs. Based on 200 outcrops of 11 rock types, the approximate mean susceptibility of basalt and diabase is 2500×10^{-6} , of rhyolite and gabbro 1000×10^{-6} , of acid intrusives including granite 400×10^{-6} , of greenstone 100×10^{-6} , and of slates 50×10^{-6} . Variability is high for acid intrusives, intermediate for basalt, rhyolite, and greenstone, and lower for diabase, gabbro, and slate.

281. *Reverse Thermoremanent Magnetism.*

T. Nagata, S. Akimoto & S. Uyeda, Acad. Japan Proc., Vol. 28, No. 6, pp. 277-281, 1952.

The self reversal of thermoremanent magnetization of a hypersthene hornblende dacitic pumice from Volcano Hasuna, Japan, has been observed. This rock, when subjected to a magnetic field while being cooled from 500 to 450° C, shows normal thermoremanent magnetization, but when reheated exhibits an abnormal increase of magnetization at 450° C, similar to that proposed by Neel for P-type ferrites. When subjected to a magnetic field while being cooled from 300 to 250° C, the rock demonstrates reverse thermoremanent magnetization with a positive temperature coefficient of magnetization marked by larger than the negative temperature coefficient of the normal thermoremanent magnetization. This suggests that N- or V-type ferrites exist in the specimen and possibly are responsible for the reverse thermoremanent magnetization.

282. *Magnetic Susceptibility of Ferromagnetic Minerals contained in Igneous Rocks.*

S. Akimoto, J. Geomagnetism & Geoelectricity, Vol. 3, No. 4, pp. 47-58, 1951.

The ferromagnetic minerals separated from 15 specimens of Japanese volcanic rocks were analysed chemically and the variation of their magnetic susceptibility with temperature measured. All the samples had a characteristic curve, a gentle increase of susceptibility with increasing temperature to about 400° C and then a sharp drop to the Curie point at about 500 or 600° C. Minerals from those rocks which cooled slowly from a low temperature had high susceptibility (0.10-0.12 cgs) and the curve of descending temperature matched that of ascending temperature (a reversible curve). Minerals from the rocks which cooled rapidly from a relatively high temperature had low susceptibility (0.02-0.03 cgs) and demonstrated both reversible and irreversible curves. Intermediate samples showed high susceptibility of the irreversible type. The irreversible characteristic of the curves is attributed to the redistribution of the FeO, Fe₂O₃, and TiO₂ in complex ferromagnetic minerals other than the magnetic and ilmenite which produce reversible curves.

Measurements on powders of different grain size prepared from the same specimen show that the susceptibility decreases by a factor of about 2 for a decrease in the grain size of 100. The susceptibility is also reduced as the amount of TiO₂ is increased.

283. *On the Magnetic Susceptibility of Soil* (In French).
E. Le Borgne, Acad. Sci. Paris Comptes Rendus, Vol. 235, No. 18, pp. 1042-43, 1952.
The magnetic susceptibility of samples of granite, schist, and soil from areas around Pontivy and between Quimper and Quimperle was determined. The susceptibility of the schist ranged from 8 to 18×10^{-6} , and of the granite from 5 to 14×10^{-6} . The susceptibility of the soil was in general greater than that of the underlying rocks, being of the order of 10^{-4} and sometimes reaching 10^{-3} cgs.
284. *On the Origin of Inverse Magnetization Observed in the Rocks of Auvergne* (In French).
A. Roche, Acad. Sci. Paris Comptes Rendus, Vol. 236, No. 1, pp. 107-9, 1953.
Rocks from the Monts d'Auvergne, France, showing reverse remanent magnetization have been heated to the Curie point and then cooled in a magnetic field. The rocks showed a slow steady decrease of magnetization with increased temperature and when cooled took on a magnetization of the same direction as that of the applied field. In addition to claystone beneath basalt flows and the calcareous marl adjacent to a basalt dyke have the same reverse remanent magnetization as the basalt. In two of these instances it has been shown that the minerals contained in the claystone are syngenetic and are not related to the vulcanism. Apparently these reverse magnetizations cannot have been produced by the mechanisms proposed by Neel but must represent real reversals of the Earth's magnetic field at the time these rocks cooled.

ELECTRICAL

285. *Limitations on Resistivity Methods as Inferred from the Buried Sphere Problem*.
R. G. van Nostrand, Geophysics, Vol. 18, No. 2, pp. 423-433, April, 1953.
The study of resistivity surveys over buried spheres is facilitated by the use of a bipolar coordinate system. Without solving the incident potential problem entirely, the author obtains an exact solution for the apparent resistivity as measured by the Wenner configuration of electrodes situated directly over a buried conducting sphere. From a study of depth profiles over a set of spheres buried at different depths, it is concluded that one cannot expect to find by direct current methods a sphere buried to a depth greater than the radius of the sphere. This result is generalised to include bodies of more arbitrary shape.
286. *A Method for Measuring the Electrical Conductivity of Diamond Drill Core Specimens*.
S. H. Ward, Geophysics, Vol. 18, No. 2, pp. 434-447, April, 1953.
Conductive methods for measuring electrical conductivity are unsatisfactory for testing diamond drill core specimens of metallic ores. An inductive method which avoids many of the inherent difficulties of the conductive methods is described. The method consists of measuring the change of impedance of solenoid when a core specimen is inserted in it. A correlation between the change of impedance of the solenoid and the physical properties and dimensions of a spherical core is achieved mathematically. This result is extended, empirically, to include cylindrical cores. A convenient way to make the required measurements is outlined, followed by a description of the design of a particular inductive conductivity meter. Sample results obtained with this instrument are presented, and one application of the method is mentioned.
287. *Patents*. Abstracts in Geophysics, Vol. 18, No. 2, p. 459, April, 1953.
U.S. 2,613,247. 7 Oct., 1952. Method of electrical prospecting using electrodes on the surface and in a borehole.

- U.S. 2,613,250. 7 Oct., 1952. Method of measuring the resistivity of a core sample by passing current through it and noting potential drop between certain sections.
- U.S. 2,619,520. 25 Nov., 1952. A d-c electrical prospecting method in which measured potentials are integrated during short observation periods.
- U.S. 2,623,097. 23 Dec., 1952. Electrical prospecting method, using Telluric currents.
- U.S. 2,623,924. 30 Dec., 1952. Airborne electromagnetic prospecting system using energized transmitting and receiving coils.

288. *Transient Coupling in Grounded Circuits.*

J. R. Wait, *Geophysics*, Vol. 18, No. 1, pp. 128-141, January, 1953.

Transient coupling between insulated circuits of finite length grounded at their end points in an infinite homogeneous and conducting medium is investigated. The general result is specialized to the case of a typical electrode array as used in electrical resistivity logging in wells or drill holes. A graphical example shows how the voltages build up to their static value due to a suddenly applied current.

289. *The Practical Value of an Earth Resistivity Method in Making Subsurface Explorations*, in *Symposium on Surface and Subsurface Reconnaissance*.

W. F. Abercrombie, Amer. Soc. for Testing Materials, Special Tech. Pub. 122, pp. 136-141, 1952.

A discussion of the resistivity method as used by the Georgia Highway Department. Ten examples are given of tests made in the state.

290. *Earth-Resistivity Tests Applied to Subsurface Reconnaissance Surveys* in *Symposium on Surface and Subsurface Reconnaissance*.

R. W. Moore, Amer. Soc. for Testing Materials, Special Tech. Pub. 122, pp. 89-103, 1952.

A review of the use of resistivity surveys as a reconnaissance method in problems of highway engineering, location of construction materials, bridge- and tunnel-construction sites, and similar engineering problems. Examples are quoted largely from the work done by the Bureau of Public Roads.

291. *Electrical Resistivity Geophysical Method as applied to Engineering Problems*, in *Symposium on Surface and Subsurface Reconnaissance*.

H. L. Scharon, Amer. Soc. for Testing Materials, Special Tech. Publ. 122, pp. 104-114, 1952.

The electrical-resistivity geophysical method has been used with success in solving problems of the location of subsurface waters, thickness of unconsolidated sediments or overburden, buried channels, and other geologic conditions directly related to construction-engineering problems. This paper presents a brief account of the electrical-resistivity method and gives several examples to demonstrate its application.

292. *Relations between Electrical and Gravity Anomalies* (In Russian).

Iu. P. Bulashevich, Akad. Nauk SSSR, Ural'skiy Filial, Trudy Gorno-Geol. Inst. Vyp. 19, Geofiz Sbornik No. 1, pp. 3-13, 1950.

Certain relations between gravity and magnetic anomalies have been long established. In the present study approximate correlations are established between electrical anomalies in a homogeneous field and corresponding magnetic anomalies, and through them with gravity anomalies. This correlation is only valid under certain conditions of the distributing body and the magnetizing field. The derivation is made by replacement in the potential equation of magnetic susceptibility by dielectric constant and of the intensity of magnetic field by that of electrostatic field. The effect of the boundary

surface ground-air on data characterizing the electric field and the necessary corrections are also discussed.

293. *Electrical Resistivity Studies of Subsurface Conditions near Antigo, Wisconsin*.
H. C. Spicer, U.S. Geol. Survey Circ. 181, p. 19, 1952.

Resistivity measurements were made in a glaciated area near Antigo to locate buried sand and gravel deposits which might be developed as aquifers and to determine depth of bedrock. It was found possible to differentiate glacial deposits by means of these resistivity measurements and to determine the depths to, and thicknesses of, materials, as well as depth to the pre-Cambrian bedrock. It was also possible to evaluate the character of the glacial material from their electrical resistivities and to recommend the most suitable sites for drilling water-supply wells.

294. *A New Aspect of the Natural Electric Field in the Earth* (In Russian).
A. V. Veshev, A. S. Semenov & M. E. Novozhilova, Dokl. Akad. Nauk SSSR, Vol. 87, No. 6, pp. 939-41, 1952.

Anomalies in the field along a given profile are correlated in their magnitude with changes of temperature of the earth. It is suggested that the anomalies are caused by local variations in the composition of the rock.

295. *Goelectrical Methods in Exploration for Water — A Critical Attitude* (In German).
S. Thiele, Bohrtechnik-Brunnenbau, Jahrg. 1, Heft 4, pp. 98-104, 1950.

Application of goelectric methods to ground-water exploration is limited because the quantity measured, the apparent resistivity, is actually a composite of at least four independent variables. Mathematically it is valid if three of these are negligible, and in actual practice such cases are the exception, not the rule. Intensive research on the effects of these factors (textures, degree of saturation, chemical differences between connate water and ground water, resistivity of the rock without ground water) would be highly desirable.

296. *Results and Limitations of Goelectric Methods in Ground Water Prospecting* (In German).

H. Thiele, Bohrtechnik-Brunnenbau, Jahrg. 2, Heft 7, p. 9, 1951.

The state of goelectrical methods in ground-water exploration is reviewed, using detailed examples from Frankfurt am Main, north German glacial diluvium, and the North Sea marshes. Eight factors that limit their efficiency are listed. It is concluded that goelectric methods alone are reliable in determining depth, thickness, and extent of beds bearing or trapping ground water, in finding buried structures favourable for ground-water accumulation, in determining belts where a deposit is protected from contamination by a shallow clay cover, and in locating boundaries between salt water and sweet water. A combination of a few strategically placed borings with goelectric methods guarantees a complete, trustworthy, and precise, as well as cheap, method of prospecting.

297. *Hydrology, Geologic Structure, and Electrical Conductivity of the Ground in Northern Germany* (In German).

S. von Bubnoff, Deutsche Akad. Wiss. Berlin, Sitzungsber. Kl. Math.-Naturwiss., No. 1, p. 43, 1952.

From 1939 to 1944 numerous electrical resistivity surveys were made in Pommern province, mostly in search of water. An interpretation of the results is presented and compared with the geologic evidence of the region which has been thoroughly studied. Many exploratory holes were drilled to check geophysical interpretations. Many profiles are given and compared with graphs made from the measurements.

298. *The Disturbance of the Field of Direct Current Caused by Conductors Placed in Heterogeneous Semispace* (In Russian).

I. K. Ovchinnikov, Akad. Nauk SSSR Izv. Ser. Geofiz., No. 1, pp. 48-60, 1953.

Several areas in the Ural'skiy Khrebet were surveyed by the electric resistivity method, and the results were investigated theoretically by computing the pattern of the electric field around disturbing bodies, (assuming them to be perfectly conductive, as they are mostly sulphide complexes with conductivity 100 to 1000 times greater than that of the surrounding formations). The ground was assumed to be either a homogeneous semispace with constant conductivity or with conductivity varying with depth, according to certain formulae. Comparison of field measurements with the computations for a sphere and a flattened ellipsoid shows that in eight cases one of the formulae gave satisfactory agreement; in 24 cases another formula was better. It is suggested that these formulae should be further tested.

299. *Criteria and Construction Problems of Instruments for Measuring Resistivity* (In Italian).

L. Solaini, Ann. Geofis., Vol. 5, No. 3, pp. 357-365, 1952.

Because of the problems arising when great vertical depths are involved in geophysical exploration, the author recommends that instruments for measuring resistivity use alternating currents for low frequency and not too high intensity, with the potential electrodes fixed and close together. Possible solutions for the potential measuring circuits are discussed.

300. *Experimental Measurements on the Applicability of Low Frequency Alternating-current in Earth-Resistivity Apparatus* (In Hungarian with summaries in Russian and German).

K. Sebestyen, Magyar Allami Eötvös Lorand Geofiz. Intezet Geofiz. Közlemenyek, Kötet 1, Szam 9, pp. 81-88, 1952.

A report on the results obtained by members of the Hungarian Geophysical Institute during experimental measurements, using a specially constructed alternating-current resistivity equipment. It is concluded that the new instrument is very useful for exploration of shallow geologic structures.

GEOCHEMICAL

301. *An Interfering Factor in Geochemistry.*

R. L. Slobod, Petroleum Engineer, Vol. 25, No. 5, pp. B 129-135, May, 1953.

By use of the mass spectrometer the presence of nitrous oxide in soil air and soil gas samples has been confirmed. In all of the soil air samples analyzed (58) nitrous oxide was found to comprise 50% more of the "condensable" gas fraction. Although hydrocarbons can be differentiated from the nitrous oxide if combustion methods are used and are carefully interpreted, it appears to be practically impossible to separate nitrous oxide from ethane by the usual physical methods used because of the closeness of their boiling points (both boil at approximately -89° C). It is suggested, therefore, that nitrous oxide may have comprised a substantial part of the "ethane" reported in geochemical studies where combustion methods were not used to effect a separation of these gases.

302. *Geochemical Prospecting for Copper at Ray, Arizona.*

O. M. Clarke, Jr., Economic Geology, Vol. 48, pp. 39-45, Jan.-Feb., 1953.

Copper assays of oak and mesquite and the soil derived from them were made from trees growing over the Ray orebody and vicinity. Results show a marked increase of copper in plants and soil over the orebody as compared with samples taken

from areas beyond the limits of mineralization. The copper content of trees growing in the stream bed below the orebody was lower than expected. Soil assays are affected by type of rock, drainage and extent of leaching. High erroneous assays are found in regions contaminated by smelter smoke.

303. *Geophysical Prospecting of the Yugashima Gold Mine* (In Japanese with English summary).

S. Kunori & T. Saito, Geol. Survey Japan Bull., Vol. 3, Nos. 4-5, pp. 28-34, 1952.

Gold and silver occur in veins with gangue minerals of quartz, calcite, and rhodochrosite. Gamma-ray and geochemical methods gave most satisfactory results.

OTHER METHODS

304. *The Airborne Radiation Detector.*

Atomics and Atomic Technology, Vol. 4, No. 6, pp. 140-141, June, 1953.

A brief review of the construction and operation of a new instrument for use in making aerial surveys to locate radioactive deposits.

305. *Propagation of Radio Waves over a Stratified Ground.*

J. R. Wait, Geophysics, Vol. 18, No. 2, pp. 416-422, April, 1953.

See A.I.O.C. Geophys. Abstr. 385.

306. *Patents.* Abstracts in Geophysics, Vol. 18, No. 2, p. 460, April, 1953.

U.S. 2,617,945. 11 Nov., 1952. Airborne gamma-ray prospecting system with height correction device.

307. *Description of a Simplified Apparatus for Gamma Radiosondage used for Mine Survey* (In French).

J. Berbezier & C. Lallement, Ann. Geophys., Vol. 8, No. 3, pp. 314-315, 1952.

Details are given of two equipments designed for use in mines comprising a Geiger counter on the end of a suitable cable and a simple integrating detector. One form of apparatus is suitable for use in vertical shafts and the other in horizontal shafts.

308. *Oil Prospecting with the Radioactive Method.*

H. Lundberg & George Isford, World Petroleum, Vol. 24, No. 7, pp. 40-42, July, 1953.

Airborne scintillation detectors have been adapted for indicating the presence of oil. A great number of known oil fields were flown to gain sufficient material for working out rules and principles of interpretation. Surveys of unknown territory have since shown good results. Examples of repeated flights with an up-to-date airborne scintillometer, along a line across the Redwater oil field in Alberta, are shown. They are found to agree with results obtained from observations on the ground with a commercial scintillometer.



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